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Pavement Thickness Determination and Detection of Pavement Cavities Using Radar

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Pavement Thickness Determination And Detection of Pavement Cavities Using Radar

Author(s): T. Chung, Sr. Research Engineer
C.R. Carter, Professor, Communications Research Laboratory, McMaster University

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Contact Person: Tony Masliwec, Materials Research(416) 235-4689

Abstract: The determination of pavement thickness and detection of defects underneath pavement slabs are important for many pavement management decisions. Methods currently used to assess these two factors are usually destructive, time consuming and costly.

This report discusses the use of MTO's radar-based DART for pavement condition surveys. Two pavement test sites were selected for the feasibility studies. Algorithms were developed to process the radar waveforms collected from the pavement. The results show that impulse radar can be used as a non-destructive tool to measure the thickness of pavement slabs and as a remote-sensing device to assess subsurface defects such as pavement cavities caused by transverse cracking.

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T. Chung
Senior Research Engineer

C. R. Carter
Professor
Communications Research Laboratory
McMaster University

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The Editor, Technical Publications
Room 320, Central Building
1201 Wilson Avenue
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Telephone: (416) 235-3480
Fax: (416) 235-4872

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Executive Summary

Background

The current methods of pavement thickness determination and pavement cavity detection are destructive, slow and expensive. In the search to find an improved method to conduct pavement condition surveys, the use of MTO's radar-based DART was explored. Two test sites were selected to study the performance of the impulse radar on pavement. Algorithms were developed to process the radar waveforms. The results show that impulse radar can provide a non-destructive measurement of the pavement thickness and a remote-sensing assessment of the pavement cavities caused by transverse cracking.

Objectives

The primary objectives of the project included:

1. Using the existing DART system to collect data from two pavement test sites: the pavement on Hwy. 7/Dufferin Street in Thornhill and the pavement on Hwy. 12/400 in Cold Water.

2. Developing algorithms to process the radar waveforms obtained from the test sites.

3. Evaluating the effect of variable vehicle speed for collecting data.

4. Computing the pavement thickness and comparing the results with the actual measurements.

5. Examining the radar signatures from different types of transverse cracks.

Summary of Results

1. The sets of radar data collected, using the MTO's radar-based DART, from the pavement on Hwy. 7/Dufferin Street in Thornhill and Hwy. 12/400 in Cold Water were processed by a special software package which is developed for assessing the pavement structure.

2. The computed asphalt thicknesses based on the radar evaluation correlate well with the actual measurements obtained from the pavement structures.

3. Variable vehicle speed for collecting data was investigated. It has been proven that sampling data once every 10 cm requires the van to travel at a speed of no more than 5 km/h.

4. Radar waveforms obtained from regions exhibiting transverse cracking were examined. It has been demonstrated that impulse radar is capable of locating pavement cavities caused by transverse cracking.

1/ Introduction

1.1/ Background

The thickness of pavement structural layers, particularly the top layer (e.g. Asphalt Concrete), is an important parameter used for many pavement management decisions. It is used for pavement performance prediction, selection of maintenance and rehabilitation treatments, and is a basic quality control characteristic. The current methods of thickness determination - coring and/or augering - are destructive, slow and expensive.

The detection of pavement defects underneath thick pavement slabs (Portland Cement Concrete or Asphalt Concrete), particularly in the vicinity of transverse cracks, is necessary for cost-effective rehabilitation design. The large-scale use of destructive methods is impractical.

1.2/ Objectives

The project objectives included the following:

1. Modify the existing MTO's radar-based DART technology in order:
    a) to enable accurate measurements of asphalt concrete thickness for conventional pavements and,
    b) to provide a reliable detection of pavement defects beneath Asphalt Concrete slabs.
2. Investigate the possibility of using MTO's radar-based DART technology to determine thickness of all pavement structural layers.

1.3/ Proposed Approach

Preliminary tests conducted have shown close correlation between asphalt concrete thickness measured by impulse radar and by coring (see Table 1). It is proposed that the technology be exploited to its fullest by dividing the project into two phases which are:

1.3.1/ Phase One - Initial Data Collection and Interpretation

Since there are virtually no data available at the present time, it is proposed:

a) that a representative set of radar data be collected with the related core samples and any other physical information in order to facilitate waveform interpretation.

b) that vehicle speed and the related factors such as antenna bounce, smearing of the data, and number of footprints per metre be evaluated.

1.3.2/ Phase Two - Data Processing and Software Development

Using the representative data set, it is proposed:

a) that software be written to fully exploit the processing power of the DART system in parameter estimation and feature extraction.

b) that the processing take such factors into account as line length, data length, tape capacity, computer memory capacity, interfacing (tape to memory, memory to disk), distance measurement integrity and reference point evaluation, number of lines per lane, number of lanes per highway and the related line synchronization problem.

c) that on site processing versus off-line processing be evaluated taking factors such as computer speed and capability into account.

2/ Impulse Radar and Waveform Analysis

Impulse radar has been used in a wide variety of applications [1, 2] such as locating geological structures [3-5], detecting underground pipes and cables [6], measuring platform height above the ocean surface [7], detecting cadavers [8, 9], and more recently evaluating bridge decks [10-13] and pavements [14-17].

During the past seven years, the MTO DART system has proven that impulse radar has certain advantages over other conventional techniques. Firstly, the radar can be exploited to assess a number of important features concerning the condition of concrete bridge deck slabs covered with bituminous surfacing [18-27]. By identifying reflected waveforms from different layers, it is possible to extract features of the deck such as asphalt thickness, concrete cover over reinforcement, and deterioration including delamination, debonding and scaling. Secondly, the method is non-destructive and a large amount of data can be collected in a relatively short time.

The application of impulse radar for evaluating asphalt-covered bridge decks can be extended to pavement management.

2.1/ Impulse Radar

Impulse radar is particularly useful in the remote sensing of objects that are buried, encased in concrete or other material, and those hidden behind walls or other structures. The radar system used by DART is a Model PS-24 impulse radar purchased from Penetradar Corporation of Niagara Falls, New York [28]. The radar is monostatic with the antenna design based on the constant flare-angle, variable-width open horn. With the antenna 15 cm above the ground, the footprint of the antenna is about 30 cm by 15 cm with the electric field being parallel to the narrow dimension. The antenna is mounted with the larger dimension giving width so that the swath produced along a line covers the maximum area. The generated pulse is a monocycle with a pulse width of approximately 1 ns and a pulse repetition rate of 5 MHz. Essentially, the antenna differentiates this monocycle, producing the ideal symmetric impulse shown in Figure 1. The reflected signal is sampled much like in a sampling oscilloscope using the sliding gate technique and producing an output voltage pulse waveform of approximately 1 ms duration [28]. To avoid confusion, all plots are presented using the nanosecond scale.

The actual transmitted radar waveform can be obtained by positioning the antenna directly over a thin metal plate (which is much larger in dimension than the antenna footprint) on the asphalt surface and obtaining the reflection, as illustrated in Figure 2. The peak at A represents the electric field strength at the asphalt surface and provides a calibration measurement for evaluating the relative dielectric constant of asphalt which is needed for the asphalt thickness measurement. This waveform is not, however, the true reflected radar waveform. For an ideal transmitted radar signal, the two negative peaks at P and Q are expected to have comparable magnitude, as illustrated in Figure 1, and the portion from 0 ns to S and U to 20 ns in Figure 2 should be null. These imperfections are caused by the reflections which are generated inside of the antenna. In addition, when the antenna is mounted on the van, further small changes to the waveform take place due to the presence of the van itself. Thus, it is necessary to remove imperfections from the received waveform in order to obtain an accurate radar reflection. The procedures of waveform subtraction have been discussed in [24]. The corrected waveform is given in Figure 3.

2.2/ Waveform Analysis

It is possible to gain some insight as to the type of waveforms to be expected simply by considering the transmission and reflection of the radar impulse travelling from air into asphalt concrete and reflecting from the gravel. A cross-section of a simplified pavement structure is given in Figure 4. When the incident electric field (plane wave) reflects from the asphalt concrete (henceforth referred as asphalt) surface, there is a 180 degree phase shift since the relative dielectric constant of asphalt (approximately 6) is higher than that of air (unity). The incident wave propagates through the asphalt resulting in another reflection at the asphalt-gravel interface, again with a 180 degree phase shift relative to the incident wave assuming the relative dielectric constant for gravel is higher than that of asphalt. The incident wave continues to propagate through the gravel to the subgrade where a third reflection occurs also with a 180 degree phase shift relative to the incident waves.

The resulting waveforms are shown in Figure 5. The reflections from the air-asphalt interface, the asphalt-gravel, and the gravel-subgrade interface all have the same orientation, namely 180 degrees out of phase with the incident electric field. Adding these waveforms leads to the composite waveform shown which has an initial peak at A from the air-asphalt interface, a second peak at C from the asphalt-gravel interface and a third peak at D from the gravel-subgrade interface.

Since the radar converts electric field into voltage, the equation for the reflected signal voltage, r(t), is given by:

$$\begin{aligned} r(t) = {} & \rho_1 s(t) + \rho_2(1 - \rho_1^2)CF_1 s(t - 2T_a) + \\ & \rho_3(1 - \rho_2^2)(1 - \rho_1^2)CF_2 s(t - 2T_a - 2T_g) \end{aligned} \tag{1}$$

$s(t)$ = incident signal voltage
ρ_1 = reflection coefficient from air to asphalt
ρ_2 = reflection coefficient from asphalt to gravel
ρ_3 = reflection coefficient from gravel to subgrade
T_a = one-way time delay in asphalt of thickness D_a
T_g = one-way time delay in gravel of thickness D_g
CF_1 = calibration factor for the reflection from the asphalt-gravel interface
CF_2 = calibration factor for the reflection from the gravel-subgrade interface

The calibration factors related to (1) have been discussed in [27]. Normally, the asphalt thickness lies in the range of 50 to 150 mm. Thus, waveforms of the type shown in Figure 5 should be a typical representation for the pavement structure.

The reflection coefficients can be calculated, assuming lossless material, by the well-known relation [29],

$$\rho = \frac{Z_L - Z_S}{Z_L + Z_S} \tag{2}$$

where Z_L is the load impedance and Z_S is the intrinsic impedance of the source medium. For a dielectric medium, such as asphalt, the impedance is denoted by,

$$Z = \frac{Z_o}{\sqrt{\epsilon_r}} \tag{3}$$

where Z_o is the free space impedance having the value of 377 Ω and ϵ_r is the relative dielectric constant of the medium.

The thickness of the asphalt (D_a) is simply the product of half the time delay between peaks A and C ($2T_a$), and the velocity of propagation in asphalt ($c/\sqrt{\epsilon_a}$) where c is the velocity of light and ϵ_a is the relative dielectric constant of asphalt which can be determined using relations in (6) and (7),

$$D_a = \frac{T_a\, c}{\sqrt{\varepsilon_a}} \tag{4}$$

Since the sampling rate used for the radar signal is 25000 samples per second, the asphalt thickness in mm becomes,

$$D_a = \frac{6\, N_a}{\sqrt{\varepsilon_a}} \tag{5}$$

where N_a is the number of samples between peaks A and C. It is noted that the resolution in evaluating the thickness of asphalt according to (5) is restricted by the pulse-width of the impulse radar signal. The relative dielectric constant of asphalt ranges from 4 to 10 with a value of 6 being quite common. It is found that if the asphalt thickness exceeds 30 mm and ε_a is at least equal to 6, there is little difficulty in evaluating D_a. Actual comparisons of radar measured asphalt thickness from DART and core samples, show an accuracy of approximately ±5% to ±8%.

The relative dielectric constant of asphalt can be calculated by first measuring the reflection coefficient at the air-asphalt interface (i.e. ρ_1). Note that ρ_1 is the negative of the ratio of the voltage amplitude at peak A (V_2) from the air-asphalt interface divided by the amplitude at peak A (V_1) from the metal plate, which are both measured values. Thus,

$$\rho_1 = -\frac{V_2}{V_1} \tag{6}$$

Once the value of ρ_1 is determined, it is an easy matter to calculate ε_a through the relation,

$$\varepsilon_a = \left[\frac{1 - \rho_1}{1 + \rho_1}\right]^2 \tag{7}$$

From actual measurements, the composition of asphalt is found to vary from area to area. Thus, it is necessary to calculate ε_a for each location.

3/ System Configuration and Software Development

For the measurement of pavement thickness, data collection is performed using the 386-based DART system. Originally designed to perform bridge deck condition analysis, the DART software required modification in order to perform pavement studies.

3.1/ System Configuration

A block diagram, given in Figure 6, illustrates the configuration of the 386-based computer system. The hardware includes:

- an industrial computer with 386-20 MHz CPU
- a 387-math coprocessor
- a 16 Mb system memory and one 150 Mb hard drive
- one DT2821 data acquisition interface card
- one 5-1/4" 360 Kb and one 3-1/2" 1.44 Mb floppy drives
- one VGA video card and one enhanced keyboard
- one NEC Multisync 2A monitor with monitor mounting kit
- one FUJITSU model DL2600 line printer
- one HP model 7475A plotter
- one Tektronic model 2245A 100 MHz oscilloscope

The combination of the 386-computer operating at 20 MHz and the DT2821 A/D interface card allows the radar data to be digitized in real-time, i.e. data collection can be achieved by directly sampling radar signals into the computer memory. Once data are stored in the computer, they can be made portable using floppy diskettes. Also, the data in digital format are more reliable than the tape recorded analog signal. It has been found that the quality of the tape recorded signal often reduces the effectiveness and accuracy of the system.

The DT2821 card is characterized by the following specifications: A/D throughput rate of 50 kHz; 16 single-ended or 8 differential A/D input channels; 12 bits of resolution; inputs of 0-10 V unipolar or ±10 V bipolar; programmable gains of 1, 2, 4 and 8; and two D/A channels with 12 bits resolution. The procedure for real-time data acquisition is to program the DT2821 interface board using the ATLAB software routines [28]. The DT2821 contains dual DMA channels which support continuous performance data collection [29]. Continuous performance is a data sampling method which provides gap-free transfers of large volumes of data to/from memory or disk without any loss of samples. Each DMA buffer can be assigned anywhere in the 16 Mb system memory space of the 386-computer and can be up to 64 K words long.

The ATLAB is a real-time software package providing a high level language interface (such as Microsoft FORTRAN) to the DT2821 interface board. The software allows the user to control all the analog and digital I/O capabilities of the interface card through operation-specific subroutines. Also, the ATLAB utilizes buffers as opposed to registers. This greatly simplifies the programming, use and application of the DT2821. Some of the routines written in the ATLAB include: analog input/output; digital input/output; continuous sampling of data; DMA buffers management; and DT2821/system clock control.

3.2/ Software Development

The algorithms prepared for this project include a modified version of the DART's software [26]. Two software packages, PAVE91 and MTOSCAN written in FORTRAN 77, are discussed in the following sections and the source codes are provided in the Appendix. PAVE91 performs the data acquisition and signal processing of radar data. Basically, the data acquisition procedures are identical for both the DART and pavement projects. For pavement, only the asphalt thickness need be evaluated. MTOSCAN outputs a profile plot of the pavement by means of radar waveforms.

3.2.1/ Signal Processing Software - PAVE91

The flow diagram of PAVE91 is given in Figure 7. It is noted that the ATLAB routines initialize the system memory into 100 DMA buffers each having 50 K words. This setup is to facilitate the DT2821 data acquisition operation. Since one complete radar trace contains 512 samples (16-bit), each data buffer holds a maximum of 100 waveforms. Therefore, in order to sample the pavement once every 10 cm, the minimum and maximum distance of pavement to be sampled is 10 m and 1 km per pass, respectively.

PAVE91 requires the following inputs from the user:

- Site name
- Fifth-wheel pulse information - 1 cm, 5 cm, 10 cm or 1 m etc
- Expected distance to be covered
- Output step size for the thickness table - 1 cm, 5 cm, 10 cm or 1 m etc
- Choice of performing either data collection and signal processing or just data collection
- Thickness (mm) from asphalt core sample
- Number of passes (lines) to be collected - maximum is 16 passes
- Data sources - either supply data by direct A/D sampling or from data files

- Choice of yes/no for selecting the debugging feature for diagnostic purpose
- Antenna internal reflections data set
- Flat plate amplitude - from direct A/D sampling or from data file or from keyboard input

PAVE91 also invokes several subroutines to perform the following functions: acquiring and measuring the flat plate signal in subroutine FPLATE91; acquiring radar signals and evaluating the asphalt thickness in subroutine SIGPRO91; and, outputting the processed results in TABLE91. Each of these subroutines is now discussed.

3.2.1.1/ Subroutine FPLATE91

Twenty flat plate waveforms are acquired and averaged to provide the surface echo amplitude required for calculating the reflection coefficient at the air-asphalt interface. The DT2821 board is configured through software control by the ATLAB to have a sampling frequency of 25 kHz, and a gain of one at the A/D channel 0. Burst mode DMA operation is used for data acquisition. Upon the completion of each DMA cycle, the digitized samples are transferred from the user buffer to an extended memory buffer such that the user buffer can be released for the next DMA operation. After 20 waveforms have been sampled, the data in the extended memory buffer are transferred to the user buffer for data processing. The radar data are corrected for the antenna internal reflections using the subroutine REMIR91. The flow graph of subroutine used in FPLATE91 is given in Figure 8.

3.2.1.2/ Subroutine REMIR91

A first order subtraction of the antenna internal reflection from the raw data set is computed. The flow diagram is given in Figure 9. A set of the pre-recorded antenna internal reflection signature data is stored in the computer [24]. This data set is retrieved from the system and subtracted from each radar waveform over an 11-sample set: i) exact case - line up both waveforms with respect to the first sample; ii) left shift case - radar waveform shifted one sample to the left each time, over five iterations with respect to the first sample of the antenna internal reflection waveform and iii) right shift case - radar waveform shifted one sample to the right each time, over five iterations with respect to the first sample of the antenna internal reflection waveform. The root-mean-square (rms) values over the first 100 samples are computed and compared for the eleven cases. The corrected radar waveform is obtained by subtracting the shifted set from the entire raw data set. The subtraction is based on selecting the shift providing the minimum rms value.

3.2.1.3/ Subroutine SIGPRO91

Radar waveforms are acquired and analyzed in this subroutine. Channels 0, 1, 2 and 3 of the DT2821 A/D board are assigned for acquiring radar video, radar pre-trigger, fifth-wheel pulse and line sync signal, respectively. The digitized data are stored onto drive E (33 Mb capacity). The flow diagram of SIGPRO91 is given in Figure 10.

The steps for data acquisition are as follows:

- Initialize and reset the DT2821 board
- Set the sampling rate to 25 kHz and gain to one at all I/O channels
- Declare user buffer and assign 100 extended memory buffers
- Check for the line sync signal to go high at Channel 3
- Check for the rising edge of the fifth-wheel pulse at Channel 2
- Check for the rising edge of the radar pre-trigger signal at Channel 1
- Acquire 512 samples of radar signal at Channel 0 using DMA burst mode and store the digitized data temporarily in the user buffer
- Transfer data from the user buffer to the extended memory buffers upon the completion of each DMA cycle
- Release the user buffer for the next DMA operation
- Perform book-keeping for each extended memory buffer
- Check for the line sync to go low at Channel 3 - if the line sync is low, then terminate the data acquisition process

The steps for signal processing are as follow:

- Transfer data from the extended memory buffer to the user buffer and copy the data to drive E
- Reset all the parameters, flags and counters
- Subtract the antenna internal reflections from the radar waveforms using REMIR91
- Use subroutine PEAKC91 to locate the surface reflection peak and asphalt-gravel interface peak from each set of consecutive waveforms defined by the output step size and fifth-wheel pulses
- Average the peaks location
- Use subroutine PEAKS91 to perform a fine search of the asphalt-gravel interface peak
- Evaluate the reflection coefficient at the air-asphalt interface, relative dielectric constant of asphalt and asphalt thickness
- Calculate the average of asphalt thickness at every output step size given by the user and provide an overall summary of the processed results
- Store the processed data in data file TABLE.mto

3.2.1.4/ Subroutine PEAKC91

The surface reflection (peak A), the transient peak due to surface reflection (peak B), and the asphalt-gravel interface reflection (peak C) are identified in subroutine PEAKC91. The flow diagram is given in Figure 11. The sample locations of peak C are averaged over a set of consecutive waveforms. The average value is used for confirming the peak C locations in subroutine PEAKS91.

3.2.1.5/ Subroutine PEAKS91

A fine search of the asphalt-gravel reflection peak is performed in this subroutine using the average value of peak C obtained from PEAKC91. Other parameters, such as the relative dielectric constant of the asphalt and the asphalt thickness are also evaluated. The flow diagram is given in Figure 12.

3.2.1.6/ Subroutine TABLE91

An output of asphalt thickness in tabular format is generated. The flow diagram is given in Figure 13.

3.2.2/ Profile Plot - MTOSCAN

Consecutive radar waveforms are plotted to simulate the pavement profile. The waveforms can also be enhanced using different pre-processing techniques to yield better viewing results. The pre-processing methods include: sensitivity time control (STC) plot; threshold plot; skew plot and zoom plot. Two plotting packages are used - the PLOTMATIC graphic package is used to output plots to the HP plotter and the GRAFMATIC graphic package is used to output plots to the monitor. The flow diagram is given in Figure 14.

4/ Pavement at Highway 7 and Dufferin Street (Thornhill)

The pavement site at Highway 7 and Dufferin Street was visited twice in the last two years, October 1989 and October 1990. For both visits, data for the two wheel paths along the eastbound right-hand lane were collected. During the second visit, data were also collected for variable van speed tests. A cross-section of the pavement is shown in Figure 15. Originally, this section of pavement was a test site for pavement response and damage. There are numerous deflection transducers, temperature gauges, pressure gauges and strain pads embedded at different locations along the pavement. The pavement is fairly new and is in good condition. The radar scanned 600 m of pavement containing different asphalt thicknesses and materials including:

- an 80 m section of 140 mm thick asphalt over gravel over subgrade
- a 150 m section of 90 mm thick asphalt over gravel over subgrade
- a 70 m section of bare concrete
- a 150 m section of 90 mm thick asphalt over gravel over subgrade
- a 150 m section of 80 mm thick asphalt over gravel over subgrade

4.1/ Data from 1989 Survey

The two passes of data were collected using the DART's XT-based system. The radar waveforms were recorded on analog tapes and played back off-line for data acquisition (using a TECMAR interface board) and analysis [24]. Due to the limited capacity of the XT-system, the data acquisition software was designed to sample radar responses once every 20 cm. Therefore, a total of 3000 waveforms were collected from each pass of a 600 m path. The van speed was about 5 km/h.

Figure 16 shows the corrected radar waveforms obtained from the first 45 m of Line 1. Each waveform on the left is separated by 1 m (i.e. each waveform is the average of five input waveforms). The average waveform over the 45 m section is given on the right. Note that a large percentage of the radar signal strength is reflected at the air-asphalt interface where a strong echo (surface reflection) is seen at about the 5.4 ns mark. A small portion of the signal energy propagates through the asphalt layer and reflects off at the subsurface layers where two weak echoes having competitive magnitude are seen at about the 7 and 8 ns marks.

The strong surface reflection is useful for calculating the reflection coefficient at the air-asphalt interface which in turn is used to determine the relative dielectric constant of asphalt. Unfortunately, the strong surface echo is undesirable since it obscures the detection of other subsurface echoes. One method of compensating for signal strength loss is to employ sensitivity time control (STC) to the radar waveform. The radar signal is pre-processed by STC. The STC partially compensates for losses due to spherical spreading and attenuation by increasing the gain with increasing range [23]. A sliding gate gain function starting with a gain of unity at the surface echo and increasing to a gain of 10 at the trailing edge of the signal was selected.

4.1.1/ Profile Plots Using STC

Figure 17 demonstrates the effect of STC on the set of signals shown in Figure 16. The echo at the 8 ns mark becomes more pronounced than before. In addition, other subsurface echoes emerge as a result of employing STC. Also, STC is seen to provide much better profile plots which enhance visual observation. Henceforth, STC is applied to all waveforms being presented in this chapter unless otherwise stated.

Figures 18 to 30 and 31 to 44 are the profile plots of the pavement from Lines 1 and 2, respectively. By examining these plots, it is noted that the reflection at the 8 ns mark in Figures 17 and 31 are due to the asphalt-gravel interface. This is further confirmed by Figures 18 and 32 where changes in the asphalt layer thickness are very obvious starting at about 60 m. From the cross-sectional drawing (Figure 15), asphalt layer thickness at that location changes from 140 mm to 90 mm. Figures 22 and 23 from Line 1 and Figures 36 and 37 from Line 2, respectively, show the concrete section starting at 240 m and ending at 280 m. The waveforms are characterized by the absence of the asphalt-gravel interface reflection. At about 10 m beyond the concrete section, the radar signals show a great deal of turbulence which may be caused by materials (or sensors) buried underneath the asphalt layer. The section where the thickness of asphalt layer changes from 90 mm to 80 mm is identified in Figure 27 at 480 m on Line 1 and in Figure 41 (also at 480 m) on Line 2, respectively.

From the set of plots above, it is demonstrated that impulse radar can be utilized to inspect pavement structure. It is specially valuable as a non-destructive tool to identify the depth of the asphalt layer. The procedure for measuring the thickness of the asphalt layer can be easily implemented using computer automation.

4.1.2/ Asphalt Thickness Evaluation

The software package PAVE91 presented in Chapter 3 is designed to process radar waveforms and compute the thickness of an asphalt layer. The computer evaluation for the above described pavement at 1 m intervals is reported in Table 2. It is noted that the data were collected and digitized using the XT-based DART. As well, the data were processed using the new 386-based DART, since it is 25 times faster than the XT-computer [26].

The software, PAVE91, requires information about the asphalt core sample. Since, the cross-sectional drawing (Figure 15) for the pavement was available, there was no actual coring done at the site. The input to the software for the asphalt core sample was 130 mm. The relative dielectric constant of asphalt was calculated to be 11.38 which is much higher than the normal value of about 6.22. It is believed that the mix for the asphalt layer may contain highly conductive materials such as steel-slag.

The changes in the asphalt layer thickness from section to section are identified in Table 2, where:

i) for the section with 140 mm thick asphalt (from 1 m to approximately 68 m), the average thickness is computed to be 110 mm

ii) for the section with 90 mm thick asphalt (from approximately 68 m to 240 m), the average thickness is computed to be 78 mm

iii) the concrete section (from approximately 240 m to 280 m) has no asphalt (note that the thickness computed for this section is irrelevant since the asphalt-gravel interface is absent. The value of 999 is assigned by the algorithm for waveforms that cannot be processed. These include, for example, missing radar trigger; missing surface echo; missing asphalt-gravel interface peak or simply a corrupted waveform.)

iv) for the section with 90 mm thick asphalt (from approximately 280 m to 480 m), the average thickness is computed to be 83 mm

v) for the section with 80 mm thick asphalt (from approximately 480 m to 600 m), the average thickness is computed to be 74 mm

The computed asphalt thicknesses are consistently less than the actual measurements provided by the cross-sectional drawing. There are several factors that could affect the measurement. Firstly, the data were collected every 20 cm and the results were output at every 1 m, i.e. an averaging over five waveforms. It is believed that the accuracy in measurement can be increased if more waveforms are included in the averaging process (for example sample data at every 10 cm or less to yield more waveforms). Secondly, the sampling process was not in real-time, i.e. the data were recorded in analog form and data acquisition was performed off-line. It is believed that the tape recording procedures may affect the authenticity of the signal quality.

4.2/ Data from 1990 Survey

Another survey was conducted one year later at the same location. The radar data were collected and digitized (DT2821 interface board) in real-time (i.e. with no tape recording) using the new 386-based DART. Since the 386-computer has full system memory, the new data acquisition software permits the system to sample radar waveforms every 10 cm. Therefore, for one complete pass of a 600 m path there are 6000 radar waveforms. For an output at every 1 m step size, the result is an average over every 10 waveforms which is double that of the previous survey. Lines 1 and 2 on the pavement were chosen to be approximately the same path as the 1989 survey.

4.2.1/ Survey Results

Figures 45 to 56 and 57 to 68 provide the profile plots with STC of Lines 1 and 2, respectively. Each waveform is averaged over 10 radar traces and is separated by 1 m. The average relative dielectric constant of asphalt is measured to be 10.13 which is about ±5.5% different from the 1989 survey. The difference may be due to the number of waveforms used in computing the average value. (Note that data obtained from the 1990 survey was twice that collected from the 1989 survey.) Table 3 lists the results of the computed thickness of the asphalt layer, where:

i) for the section with 140 mm thick asphalt (from 1 m to approximately 70 m), the average thickness is computed to be 122 mm

ii) for the section with 90 mm thick asphalt (from approximately 70 m to 240 m), the average thickness is computed to be 88 mm

iii) the concrete section (from approximately 240 m to 295 m) has no asphalt

iv) for the section with 90 mm thick asphalt (from approximately 295 m to 490 m), the average thickness is computed to be 91 mm

v) for the section with 80 mm thick asphalt (from approximately 490 m to 600 m), the average thickness is computed to be 79 mm

It is noted that the computed measurements are much closer to the actual values indicated on the cross-sectional drawing (Figure 15) than those in the 1989 survey. The improvement in accuracy is due to the improvement in the data collection method and the increase in the size of waveforms averaging. Figure 69 compares the depth of the asphalt layer obtained from Tables 2 and 3, respectively.

4.2.2/ Threshold Plots

In measuring the asphalt thickness, both the surface echo and the asphalt-gravel interface reflection must be identified. It is known that the surface reflection is always well-defined. However, the radar signatures are shown to have numerous echoes. The main challenge is to locate the reflection from the asphalt-gravel interface. It has been shown that STC can enhance the signal interpretation. Albeit, the STC waveforms still contain unwanted clutter echoes.

One simple method of improving the output of the profile plots is to introduce a threshold to the radar waveforms. Figure 70 demonstrates the results of applying a 0.0 V threshold (i.e. only output the positive peaks) to the STC plots for the entire Lines 1 and 2, respectively. The plot shows only those positive echoes after the surface reflection. Each waveform represents 2.4 m intervals (i.e. one waveform is the average of 24 radar traces). The changes in the thickness of the asphalt layer, from section to section, become a moving target which can be easily identified on the plots between the 7 and 8 ns region.

4.3/ Variable Van Speed Results

The vehicle speed is important in the sense that it affects the overall system operation. Driving a slowly moving van (speed less than 5 km/h) to collect data for a condition survey may be unsatisfactory. Traffic closures take longer and the system is not operated at full capacity, i.e. the system is idle until the next response is available. Conversely, driving at higher speeds (over 20 km/h) causes uncertainty in the data collection including the antenna footprint smearing problem and signal distortion.

The fifth-wheel is designed to generate a pulse once every 1 cm of displacement. The duration of each of these 1 cm pulses is governed by the vehicle speed. For example, 1) if the van is moving at a speed of 5 km/h, then one fifth-wheel pulse period is 7.2 ms; and, 2) if the van is travelling at 30 km/h, then one fifth-wheel pulse period is 1.2 ms. The impulse radar illuminates targets at a rate of 50 pulses/s (i.e. 20 ms per waveform).

Within one fifth-wheel pulse the system must be able to acquire one complete radar trace, otherwise the distance information will be inaccurate. The duration of the 1 cm fifth-wheel pulse at different vehicle speeds can be easily calculated. Table 4 provides the results obtained from a simulation conducted using variable van speed and the 10 cm fifth-wheel pulses. The van speed starts at 5 km/h and increased to 30 km/h in steps of 5 km/h. The total distance travelled is 120 cm. It is assumed that both the radar trigger and the fifth-wheel pulse are initially in sync. The table also computes: i) the duration of each 1 cm fifth-wheel pulse; ii) the distance that the van travels after acquiring one radar pulse; iii) the expected number of radar pulses in 10 cm intervals; and, iv) the time required to travel the 120 cm distance. The 'RISE' and 'FALL' labels indicate the time (ms) of the rising edge and falling edge of the desired fifth-wheel pulses. The 'iON' label indicates the time (ms) of the current radar trigger. If the radar trigger is already high while the rising edge of the fifth-wheel pulse occurs, the current radar trigger will be ignored and the next radar trigger will be acquired as shown by labels 'trigB' and 'trigE' (both in ms). The 'flag' label indicates whether at each desired fifth-wheel pulse the data acquisition is successful (i.e. flag = 1). At high vehicle speed, the data acquisition time (i.e. 20 ms for a complete waveform), may not be completed before the occurrence of the next fifth-wheel pulse. In such a case, the fifth-wheel pulse will be lost (i.e. flag = 0). It is shown by the simulation that for the system to sample radar waveforms once every 10 cm, the van must be travelling under 10 km/h. Otherwise, fifth-wheel information will be inaccurate.

Figures 71 to 73 provide the results of the data acquisition of radar signals at variable van speed using the 10 cm fifth-wheel pulse. Two flat plates (61 cm square, each) were located on the pavement side by side to form an area of 120 cm by 61 cm with the larger dimension being used along the path of travel. The flat plates serve two purposes: 1) they are used as markers, so that any loss of antenna footprint can be detected easily (it is expected that for the 10 cm fifth-wheel pulse, there will be 12 antenna footprints for a distance of 120 cm); and, 2) the signal response from a flat plate is well recognized; therefore, any signal distortion due to high vehicle speed can be detected. The results show that only if the van travels at 5 km/h or less will there be no loss in antenna footprints. Table 5 computes the desired fifth-wheel pulses to be used at higher vehicle speeds. It is noted that if the van travels at 10 km/h, the radar signal must be sampled once every 20 cm; and at 20 km/h the signal should be sampled once every 50 cm.

Figures 74 to 76 show the flat plate response at each van speed. The top trace is the centre waveform obtained from the flat plate signals in Figures 71 to 73. The bottom trace is the STC waveform. It is note that there is no indication of any sign of signal distortion. The only difference among the waveforms is the variation in the surface reflection amplitude. It is believed the antenna bounce at high vehicle speed may account for the variation in the signal amplitude. This can affect the calculation for the asphalt thickness as the surface reflection amplitudes from both the flat plate and asphalt are required in order to evaluate the relative dielectric constant of asphalt.

5/ Pavement at Highways 12 and 400 (Cold Water)

Data were collected from one pass of 450 m of pavement at Highways 12 and 400 near Cold Water, in February, 1991. A visual inspection revealed that the pavement surface has many transverse cracks. Records from the Ministry showed that some of these cracks had been rehabilitated and sealed. However, numerous new cracks have formed on the pavement surface since the last Ministry survey.

5.1/ Profile Plots

Figures 77 to 85 are the STC profile plots of the data. The output follows the same format as discussed in Section 4.2. The van speed was approximately 5 km/h and the radar waveform was sampled once every 10 cm. No core sample was taken at the site, but a drill was used to bore through the asphalt layer near the 440 m section where an asphalt thickness of approximately 120 mm was obtained.

From the plots, it is noted that: 1) For the sections over the first 90 m and from 150 m to 200 m, respectively, the waveforms are quite consistent, which indicates that the subsurface condition is relatively intact. (It is noted that the cracks on these two sections have been rehabilitated and sealed with grout.); 2) For the section from 90 m to 150 m, the waveform signatures show significant changes in such a way that the subsurface is possibly different from the other sections; and 3) For the section from 150 m to 450 m, the waveforms have noticeable changes, but to a lesser degree, which indicate that the subsurface condition is not intact. (It is noted that the cracks on this section have not been rehabilitated or sealed.) Using the measurement obtained from drilling, the reflection from the base of the asphalt layer is found to be near the 7 ns region. The strong reflections beyond the 8 ns region are possibly due to the result of frost buildup in the subgrade level during the winter season. In fact, the area had experienced a winter storm one week earlier.

In order to examine the degree of change in the subsurface level, the section from 250 m to 300 m is examined. Figures 86 to 90 illustrate waveforms taken every 10 cm. Occasionally, horizontal lines are seen on the plots indicating that waveform cannot be processed because the radar trigger is out of sync with the video signal. Three locations on this section of the pavement, 255 m, 274 m and 290 m, respectively, are known to have transverse cracks. It is noted that waveforms, from the section near 255 m, indicate changes in the subsurface level where very distinctive negative-going echoes are seen at the 7.5 ns and 9 ns regions. The negative-going pulse could be caused by subsurface cavities filled with air. Waveforms from the section near 274 m also demonstrate changes in the radar signature in the region between 8 ns and 9 ns. Other locations that show waveform variations are at 260 m, 264 m, 267 m, 273 m, 276 m, 286 m, and 295 m. It is believed that a finer resolution, such as scanning the pavement once every 5 cm, would provide better assessment of the subsurface conditions.

5.2/ Asphalt Thickness

Table 6 provides the processing results for the thickness of the asphalt layer. The measurement obtained from drilling was used as the input for the asphalt core sample. The average relative dielectric constant of asphalt was found to be approximately 5.69 and the average asphalt thickness was computed to be about 111 mm. It is noted that the pavement has thinner asphalt near the beginning of the section but increases gradually toward the end of the section. This is clearly illustrated in Figure 91 where a plot of the asphalt thickness for the complete pass is given. The large values (order of 140 mm) of the asphalt thickness near the section from 70 m to 88 m can be best explained by referring to Figure 78 where the waveform signatures start to change significantly. It is worth mentioning that the computed value of the asphalt thickness at 440 m is 120 mm which agrees with the measurement done by drilling.

An STC plot with 0.0 V amplitude threshold applied to the entire data pass is shown in Figure 92. Each waveform represents 2 m separation, i.e. averaging of 20 waveforms. The reflection due to the asphalt base near the 7 ns region is relatively consistent. Variations in the subsurface level are clearly shown on the plot for the section between 90 m to 150 m.

5.3/ Cracks

Sixteen transverse cracks on the pavement surface were examined. These cracks were classified as sealed (i.e. the cracks were rehabilitated since the last survey); old (i.e. the cracks were identified from the last survey but no repair were given) and new (i.e. the cracks were formed since the last survey). The width of the cracks ranged from 2 mm to 25 mm. Basically, two types of repair had been done to the cracks. Prior to sealing with grout, the cracks had been: 1) cut to 40 mm in width and 10 mm in depth for the section from 0.0 m to 100 m; and, 2) cut to 19 mm in width and 19 mm in depth for the section from 100 m to 300 m. It is noted that the cracks in the section from 300 m to 450 m were not repaired. The radar was used to investigate whether remote-sensing assessment could be applied to subsurface damage, such as cavities, caused by cracked pavement.

For crack measurements, the van travelled at 2 to 3 km/h. The radar scanned for a 2 m distance (1 m before and after the crack) over each crack so that data could be sampled once every 1 cm. It was originally thought that the DART hardware was capable of utilizing the direct input (pulse every 1 cm) from the fifth-wheel. However, it was found that the data acquisition system was not fast enough to synchronize with the short duration of the 1 cm fifth-wheel pulses. (The fifth-wheel signals for DART have been conditioned through a custom built interface circuit so that the data acquisition system can sample data once every 10 cm, 1 m and 10 m, respectively.) As a result, the radar data and the 1 cm fifth-wheel pulses were tape recorded in analog format and were processed off-line.

In the laboratory, the tape recorded 1 cm fifth-wheel pulses were examined. It was concluded that the fifth-wheel interface circuit requires a modification in the design for the purpose of collecting data with a resolution of 1 cm. However, the design of such circuitry is not included in this study. In order to decode the tape recorded fifth-wheel pulses for processing, the existing interface circuit was adjusted without major alteration in the design so that the system could sample data once every 5 cm.

The status of each of the sixteen cracks being investigated is described in Table 7 and the waveforms (at 5 cm resolution) are presented in Figures 93 to 100. On the plots, the horizontal lines indicate that radar waveforms were not processed due to a synchronization problem. Most of the cracks give noticeable changes in the radar signatures. This is particularly true for the reflection due to the asphalt base where the amplitude level varies substantially (such as amplitude level changes and time shifts).

For cracks sealed with grout, the grout serves as an extra layer of dielectric material in addition to the asphalt. Consequently, the radar return is more predictable. The grout is rubberized material which has a relative dielectric constant value lower than that of asphalt. Consequently, the extra reflection at the grout-asphalt interface has the same polarity as the surface reflection. Since the grout is thin (ranging from 10 mm to 19 mm) in comparison with the pulse width of the radar response, the reflection at the grout-asphalt interface could be masked by the reflection at the asphalt base which has the same polarity. The resultant reflection at the asphalt base could be attenuated (through grout and asphalt) and time shifted (due to the extra layer of grout). Figures 93 and 95 to 97 demonstrate that radar waveforms reflected from sealed cracks agree with this interpretation.

The main concern with unsealed cracks is the problem of disintegration of asphalt material which can then form a cavity in the subsurface. As the dimension of the cavity expands, the asphalt structure is weakened. In the most severe case, the asphalt layer caves in, causing hazardous traffic conditions. For unsealed cracks, the radar waveforms exhibited substantial variation depending on the severity of the pavement cavities, as given in Figures 94, and 97 to 100. It is noted that waveforms from the 'old' cracks at 346 m (Figure 99) show the most variation, which may deserve prompt attention. Waveforms from the other three 'old' cracks at locations 316 m (Figure 98), 371 m (Figure 100) and 445 m (Figure 100), respectively, are less active than the crack at 346 m. Waveforms from the 'new' cracks at locations 88 m (Figure 94), 255 m (Figure 96), 328 m (Figure 98) and 352 m (Figure 99), respectively, indicate increasing activity in the subsurface level where extra echoes were found. These may have reflected off the contents (air, water or stripped asphalt) inside the cavities. The cracks at 59 m (Figure 94) and 290 m (Figure 97) give relatively consistent radar signatures indicating that the crack may have been formed recently and damage may not be extensive.

6/ Conclusions and Recommendations for Further Research

6.1/ Conclusions

It is concluded that:

1. Impulse radar evaluations obtained from the sites at Highway 7/Dufferin Street (Thornhill) and Highways 12/400 (Cold Water) correlated well with the actual asphalt pavement thickness.
2. Impulse radar can be used as a non-destructive tool to assess asphalt pavement thickness.
3. The combination of sensitivity time control and peak thresholding methods enhanced pavement profile plots by allowing the asphalt-gravel interface reflection to be clearly discernible.
4. Simulations have shown that for waveforms to be sampled at every 10 cm, the van must travel at less than 10 km/h. Otherwise, fifth wheel information becomes inaccurate. The trade off for travelling at a faster vehicle speed is reduced resolution. For example, at a speed of 10 km/h, the optimum sampling rate is every 20 cm.
5. At high vehicle speed, the surface reflection amplitude is affected by antenna bounce. The calculation for the relative dielectric constant of asphalt may be affected and, hence, the thickness measurements may differ
6. Data collection using a sampling rate of 1 cm requires a modification to the existing fifth wheel interface circuit.
7. Impulse radar possesses the capability of remote-sensing and assessing pavement cavities formed by transverse cracks.

6.2/ Recommendations for Further Research

It is recommended that:

1. A 386-based computer be configured for pavement assessment.

2. A DT2821 data acquisition system be installed for the 386-based computer.

3. Software adjustment and modification be considered to meet the requirements for pavement management.

4. A new fifth-wheel interface circuit be built to decode fifth wheel pulses less than 5 cm.

5. Data from different pavements be examined to test the robustness of the algorithms.

6. Strategies be developed to identify and assess the degree of severity of pavement cavities.

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Table 1/ Asphalt Pavement Thickness Obtained from Radar Evaluation and Coring

Spot	Radar Thickness (± 5%)	Actual Thickness (± 3 mm)
1	75 mm	85 mm
2	90	85
3	89	102
4	115	123
5	78	81
6	69	73
7	85	88
8	87	92
9	88	92
10	89	97
11	105	120
12	126	121
13	114	120
14	113	124
15	124	124
16	123	131

Table 2/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (XT-based)

```
[ SUMMARY ]

DATE =  3  6.1991          TIME = 13:54:52:70

Thornhill at Hwy 7/Dufferin, 2 lines (XT)

AVERAGE Bridge Length =     600.00 metres     NUMBER of LINES processed =  2

   METRES       1        2              METRES      1        2
-------------------------------------------------------------------------
      1.00    111 mm 102 mm              51.00    104 mm   104 mm
      2.00    108    105                 52.00    105      103
      3.00    105     93                 53.00    105      105
      4.00    105     95                 54.00    106      106
      5.00    111    104                 55.00    109      108
      6.00    111    106                 56.00    112      110
      7.00    118    108                 57.00    111      108
      8.00    114    113                 58.00    111      107
      9.00    115    111                 59.00    110      107
     10.00    116    113                 60.00    111      109
     11.00    117    115                 61.00    113      108
     12.00    115    114                 62.00    113      106
     13.00    114    112                 63.00    111      106
     14.00    113    110                 64.00    109      102
     15.00    112    105                 65.00    105       99
     16.00    112    109                 66.00    103       94
     17.00    114    109                 67.00    103       95
     18.00    117    108                 68.00     95       91
     19.00    114    110                 69.00     88       84
     20.00    116    109                 70.00     87       88
     21.00    115    109                 71.00     85       80
     22.00    114    104                 72.00     87       83
     23.00    111    104                 73.00     86       80
     24.00    107    105                 74.00     84       75
     25.00    116    104                 75.00     83       74
     26.00    115    106                 76.00     81       72
     27.00    116    110                 77.00     81       70
     28.00    116    113                 78.00     82       72
     29.00    118    112                 79.00     84       75
     30.00    118    112                 80.00     83       74
     31.00    118    112                 81.00     83       74
     32.00    114    112                 82.00     83       76
     33.00    113    112                 83.00     85       81
     34.00    112    108                 84.00     86       84
     35.00    109    108                 85.00     87       83
     36.00    107    105                 86.00     83       86
     37.00    106    105                 87.00     82       83
     38.00    105    105                 88.00     84       83
     39.00    107    105                 89.00     84       82
     40.00    112    110                 90.00     81       78
     41.00    111    106                 91.00     78       77
     42.00    111    104                 92.00     83       83
     43.00    114    108                 93.00     85       82
     44.00    116    110                 94.00     80       80
     45.00    116    108                 95.00     80       79
     46.00    115    110                 96.00     81       76
     47.00    115    114                 97.00     83       75
     48.00    112    109                 98.00     82       73
     49.00    107    108                 99.00     78       74
     50.00    107    101                100.00     72       71
```

Table 2 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (XT-based)

METRES	1	2	METRES	1	2
101.00	73 mm	73 mm	151.00	71 mm	74 mm
102.00	72	78	152.00	71	71
103.00	76	81	153.00	73	71
104.00	79	88	154.00	74	72
105.00	82	85	155.00	75	71
106.00	79	82	156.00	72	72
107.00	80	82	157.00	73	75
108.00	80	85	158.00	75	76
109.00	81	85	159.00	77	88
110.00	80	83	160.00	79	72
111.00	77	81	161.00	75	74
112.00	77	80	162.00	74	76
113.00	78	81	163.00	67	71
114.00	81	86	164.00	93	73
115.00	82	87	165.00	71	76
116.00	84	86	166.00	75	76
117.00	83	81	167.00	78	99
118.00	83	79	168.00	81	76
119.00	80	78	169.00	76	78
120.00	81	83	170.00	79	74
121.00	90	83	171.00	75	72
122.00	83	88	172.00	72	69
123.00	86	87	173.00	72	71
124.00	84	84	174.00	77	74
125.00	86	83	175.00	78	73
126.00	84	83	176.00	80	75
127.00	91	84	177.00	82	73
128.00	95	88	178.00	76	72
129.00	101	90	179.00	75	75
130.00	100	87	180.00	76	75
131.00	101	93	181.00	77	73
132.00	99	90	182.00	74	77
133.00	94	87	183.00	73	77
134.00	88	86	184.00	74	76
135.00	86	91	185.00	78	76
136.00	85	80	186.00	78	77
137.00	82	82	187.00	79	75
138.00	81	80	188.00	77	76
139.00	80	76	189.00	78	79
140.00	80	81	190.00	79	76
141.00	81	81	191.00	77	77
142.00	83	82	192.00	72	76
143.00	81	77	193.00	74	76
144.00	79	79	194.00	73	74
145.00	77	77	195.00	78	77
146.00	75	78	196.00	77	77
147.00	78	79	197.00	79	78
148.00	80	78	198.00	79	78
149.00	78	78	199.00	79	82
150.00	74	75	200.00	81	80

Table 2 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (XT-based)

METRES	1	2	METRES	1	2
201.00	83 mm	82 mm	251.00	999 mm	999 mm
202.00	83	84	252.00	999	999
203.00	83	80	253.00	999	999
204.00	83	81	254.00	999	999
205.00	83	80	255.00	999	999
206.00	82	80	256.00	999	999
207.00	80	82	257.00	999	999
208.00	77	79	258.00	999	999
209.00	76	78	259.00	999	999
210.00	77	76	260.00	999	87
211.00	75	75	261.00	999	999
212.00	71	118	262.00	111	999
213.00	68	72	263.00	119	999
214.00	69	69	264.00	999	111
215.00	69	70	265.00	999	999
216.00	67	72	266.00	999	999
217.00	72	74	267.00	999	999
218.00	69	73	268.00	999	999
219.00	70	71	269.00	999	118
220.00	72	73	270.00	999	999
221.00	74	77	271.00	999	999
222.00	75	79	272.00	999	114
223.00	79	79	273.00	999	999
224.00	78	82	274.00	999	999
225.00	79	80	275.00	999	999
226.00	79	81	276.00	999	115
227.00	73	73	277.00	999	999
228.00	78	71	278.00	999	999
229.00	79	67	279.00	999	999
230.00	78	109	280.00	999	90
231.00	76	69	281.00	110	106
232.00	76	111	282.00	118	106
233.00	78	110	283.00	73	110
234.00	72	68	284.00	81	129
235.00	74	68	285.00	81	125
236.00	76	70	286.00	74	127
237.00	80	81	287.00	108	116
238.00	95	85	288.00	135	113
239.00	90	999	289.00	129	116
240.00	115	113	290.00	999	123
241.00	999	999	291.00	146	128
242.00	999	112	292.00	107	103
243.00	999	119	293.00	130	118
244.00	999	999	294.00	132	114
245.00	999	999	295.00	83	122
246.00	999	999	296.00	120	119
247.00	999	119	297.00	122	106
248.00	999	999	298.00	106	105
249.00	999	999	299.00	110	104
250.00	999	999	300.00	102	95

Note: Thickness = 999 indicates waveforms cannot be processed.

Table 2 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (XT-based)

METRES	1	2	METRES	1	2
301.00	97 mm	91 mm	351.00	80 mm	84 mm
302.00	91	92	352.00	58	85
303.00	94	94	353.00	82	85
304.00	97	93	354.00	94	80
305.00	98	90	355.00	87	83
306.00	99	88	356.00	87	82
307.00	102	88	357.00	82	79
308.00	93	86	358.00	83	79
309.00	92	85	359.00	86	78
310.00	91	84	360.00	83	75
311.00	91	81	361.00	82	80
312.00	87	81	362.00	85	80
313.00	84	81	363.00	86	79
314.00	85	78	364.00	84	80
315.00	95	80	365.00	83	81
316.00	87	81	366.00	82	78
317.00	82	81	367.00	81	77
318.00	86	85	368.00	80	77
319.00	90	92	369.00	77	78
320.00	103	95	370.00	79	75
321.00	103	94	371.00	81	78
322.00	105	92	372.00	80	77
323.00	103	90	373.00	81	77
324.00	98	85	374.00	82	79
325.00	94	83	375.00	82	78
326.00	90	83	376.00	80	80
327.00	91	83	377.00	82	81
328.00	91	89	378.00	81	78
329.00	94	87	379.00	82	75
330.00	96	86	380.00	81	76
331.00	98	82	381.00	82	77
332.00	96	83	382.00	82	78
333.00	96	82	383.00	84	76
334.00	97	84	384.00	85	72
335.00	95	81	385.00	84	74
336.00	93	82	386.00	83	77
337.00	102	83	387.00	83	79
338.00	103	84	388.00	86	76
339.00	104	85	389.00	85	74
340.00	95	87	390.00	84	76
341.00	94	81	391.00	82	76
342.00	101	82	392.00	83	71
343.00	98	85	393.00	82	73
344.00	96	85	394.00	80	73
345.00	93	87	395.00	80	72
346.00	96	83	396.00	79	73
347.00	96	85	397.00	77	74
348.00	95	81	398.00	82	76
349.00	94	84	399.00	80	80
350.00	86	83	400.00	88	82

Table 2 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (XT-based)

METRES	1	2	METRES	1	2
401.00	89 mm	83 mm	451.00	86 mm	80 mm
402.00	87	83	452.00	86	76
403.00	90	81	453.00	81	71
404.00	87	82	454.00	80	74
405.00	84	78	455.00	81	74
406.00	83	81	456.00	81	75
407.00	83	82	457.00	81	76
408.00	82	79	458.00	81	72
409.00	86	79	459.00	82	73
410.00	86	79	460.00	80	72
411.00	90	80	461.00	79	72
412.00	87	76	462.00	76	72
413.00	88	77	463.00	80	73
414.00	84	79	464.00	77	74
415.00	82	79	465.00	75	75
416.00	83	77	466.00	75	75
417.00	81	79	467.00	75	74
418.00	81	79	468.00	74	76
419.00	82	81	469.00	77	76
420.00	84	80	470.00	78	74
421.00	82	81	471.00	76	77
422.00	84	81	472.00	76	78
423.00	87	83	473.00	80	82
424.00	84	81	474.00	81	84
425.00	85	79	475.00	83	80
426.00	83	76	476.00	82	69
427.00	83	74	477.00	71	999
428.00	80	71	478.00	108	66
429.00	75	87	479.00	65	65
430.00	73	112	480.00	67	999
431.00	76	72	481.00	999	62
432.00	74	73	482.00	999	999
433.00	77	76	483.00	61	64
434.00	85	77	484.00	63	66
435.00	86	79	485.00	67	70
436.00	82	76	486.00	67	71
437.00	85	77	487.00	70	72
438.00	83	82	488.00	70	75
439.00	81	81	489.00	72	74
440.00	88	82	490.00	74	73
441.00	89	81	491.00	73	72
442.00	91	83	492.00	74	73
443.00	88	85	493.00	79	76
444.00	90	85	494.00	82	74
445.00	87	88	495.00	91	72
446.00	85	87	496.00	83	72
447.00	85	82	497.00	82	73
448.00	86	82	498.00	85	73
449.00	86	82	499.00	83	70
450.00	91	83	500.00	76	68

Table 2 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (XT-based)

METRES	1	2	METRES	1	2
501.00	77 mm	67 mm	551.00	78 mm	71 mm
502.00	79	111	552.00	75	72
503.00	77	119	553.00	76	70
504.00	74	121	554.00	74	71
505.00	72	999	555.00	70	69
506.00	120	999	556.00	68	70
507.00	73	999	557.00	64	73
508.00	73	106	558.00	68	70
509.00	71	105	559.00	68	999
510.00	69	101	560.00	66	109
511.00	70	999	561.00	68	63
512.00	71	69	562.00	999	63
513.00	71	68	563.00	73	999
514.00	72	68	564.00	72	999
515.00	71	69	565.00	66	64
516.00	71	70	566.00	88	70
517.00	69	67	567.00	98	62
518.00	67	999	568.00	102	999
519.00	102	999	569.00	104	999
520.00	69	66	570.00	999	105
521.00	92	69	571.00	101	999
522.00	66	999	572.00	99	102
523.00	66	69	573.00	999	102
524.00	64	69	574.00	999	999
525.00	66	70	575.00	60	56
526.00	64	69	576.00	60	65
527.00	65	68	577.00	61	83
528.00	999	69	578.00	68	82
529.00	105	66	579.00	82	85
530.00	68	65	580.00	81	84
531.00	68	108	581.00	83	85
532.00	68	107	582.00	83	82
533.00	69	105	583.00	83	81
534.00	69	109	584.00	84	80
535.00	75	104	585.00	82	84
536.00	74	65	586.00	86	93
537.00	74	69	587.00	88	97
538.00	79	72	588.00	90	96
539.00	79	71	589.00	92	92
540.00	82	73	590.00	92	84
541.00	85	73	591.00	88	76
542.00	86	74	592.00	83	68
543.00	86	72	593.00	77	67
544.00	86	74	594.00	66	68
545.00	85	73	595.00	65	69
546.00	86	75	596.00	61	71
547.00	84	74	597.00	60	75
548.00	81	77	598.00	64	74
549.00	81	75	599.00	66	72
550.00	79	73	600.00	68	72

Table 2 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (XT-based)

```
 [ OVERALL SUMMARY ]

Thornhill at Hwy 7/Dufferin, 2 lines (XT)

DATE =  3  6.1991          TIME = 13:54:55:67

[ FLAT PLATE AMPLITUDE ]  =   8.123434 v

[ FIFTH WHEEL ]           =      .2000 m

[ Pavement Range ]        =   600.0000 m

[ OUTPUT FORMAT ] every   =     1.0000 m

[ ASPHALT core sample ]   = 130.0 mm

[ AVERAGE DIELECTRIC CONSTANT OF ASPHALT ]

                  1       2
----------------------------------------------------------------------------
             11.38   11.39

 [ AVERAGE ASPHALT THICKNESS ]

                  1       2
----------------------------------------------------------------------------
millimetres      85      84

 [ OVERALL AVERAGE ]

 [ dielectric constant of aspahlt ] =  11.385050

 [ asphalt thickness (mm) ]         =   84
```

Table 3/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (386-based)

```
 [ SUMMARY ]

DATE =  3  6.1991            TIME = 11:12:48:37

Thornhill at Hwy 7/Dufferin, 2 lines (386)

AVERAGE Bridge Length =     600.00 metres     NUMBER of LINES processed =  2

   METRES      1       2                     METRES      1       2
-------------------------------------------------------------------------------
     1.00    120 mm 122 mm                    51.00    120 mm 119 mm
     2.00    122     126                      52.00    116     120
     3.00    112     115                      53.00    117     115
     4.00    114     114                      54.00    115     117
     5.00    121     115                      55.00    119     124
     6.00    123     118                      56.00    124     124
     7.00    131     125                      57.00    125     122
     8.00    132     127                      58.00    124     123
     9.00    133     132                      59.00    125     119
    10.00    131     131                      60.00    124     120
    11.00    133     131                      61.00    125     119
    12.00    131     122                      62.00    127     119
    13.00    129     127                      63.00    125     118
    14.00    125     123                      64.00    125     118
    15.00    126     124                      65.00    118     116
    16.00    127     123                      66.00    114     111
    17.00    127     124                      67.00    110     111
    18.00    131     125                      68.00    109     111
    19.00    127     122                      69.00    100     106
    20.00    132     118                      70.00     98     102
    21.00    128     118                      71.00     96     100
    22.00    128     117                      72.00     94      92
    23.00    126     117                      73.00     96      90
    24.00    120     119                      74.00     95      87
    25.00    108     115                      75.00     92      83
    26.00    129     117                      76.00     92      82
    27.00    131     119                      77.00     90      84
    28.00    131     121                      78.00     92      85
    29.00     86      83                      79.00     93      88
    30.00    134     123                      80.00     92      93
    31.00    131     123                      81.00     92      94
    32.00    129     124                      82.00     93     100
    33.00    127     120                      83.00     92     105
    34.00    123     119                      84.00     94     110
    35.00    121     118                      85.00     93     110
    36.00    119     117                      86.00     94     108
    37.00    118     116                      87.00     91     103
    38.00    118     118                      88.00     91      99
    39.00    120     116                      89.00     90      98
    40.00    124     116                      90.00     89      95
    41.00    125     122                      91.00     90      94
    42.00    124     122                      92.00     89      95
    43.00    128     124                      93.00     88      92
    44.00    130     121                      94.00     93      93
    45.00    127     125                      95.00     93      96
    46.00    129     123                      96.00     92      93
    47.00    127     123                      97.00     92      91
    48.00    127     123                      98.00     92      90
    49.00    122     119                      99.00     92      88
    50.00    123     119                     100.00     90      85
```

Table 3 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (386-based)

METRES	1	2	METRES	1	2
101.00	83 mm	86 mm	151.00	84 mm	88 mm
102.00	82	85	152.00	82	90
103.00	89	83	153.00	80	90
104.00	91	86	154.00	80	90
105.00	92	86	155.00	83	87
106.00	93	91	156.00	86	87
107.00	90	92	157.00	88	88
108.00	88	93	158.00	87	85
109.00	89	93	159.00	87	83
110.00	90	93	160.00	87	80
111.00	88	94	161.00	91	85
112.00	85	94	162.00	91	85
113.00	83	92	163.00	84	83
114.00	86	90	164.00	82	80
115.00	89	92	165.00	76	80
116.00	91	96	166.00	67	78
117.00	89	98	167.00	79	79
118.00	91	93	168.00	82	79
119.00	93	91	169.00	87	83
120.00	90	93	170.00	86	84
121.00	90	89	171.00	83	86
122.00	94	89	172.00	86	88
123.00	95	88	173.00	80	86
124.00	94	93	174.00	78	82
125.00	92	92	175.00	79	81
126.00	90	89	176.00	82	78
127.00	93	91	177.00	87	82
128.00	94	90	178.00	88	85
129.00	97	91	179.00	90	83
130.00	105	95	180.00	82	83
131.00	110	95	181.00	85	80
132.00	106	93	182.00	83	83
133.00	107	99	183.00	80	83
134.00	99	95	184.00	80	81
135.00	99	94	185.00	79	83
136.00	97	93	186.00	79	83
137.00	95	95	187.00	79	81
138.00	93	96	188.00	85	81
139.00	92	96	189.00	85	83
140.00	89	95	190.00	84	82
141.00	89	94	191.00	84	81
142.00	89	92	192.00	85	82
143.00	90	93	193.00	84	84
144.00	91	95	194.00	85	86
145.00	91	95	195.00	80	87
146.00	88	93	196.00	80	84
147.00	87	93	197.00	82	86
148.00	86	95	198.00	82	86
149.00	87	92	199.00	84	88
150.00	88	91	200.00	87	88

Table 3 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (386-based)

METRES	1	2	METRES	1	2
201.00	87 mm	87 mm	251.00	95 mm	81 mm
202.00	88	88	252.00	94	91
203.00	90	88	253.00	91	84
204.00	89	87	254.00	85	90
205.00	90	92	255.00	85	81
206.00	92	91	256.00	96	88
207.00	90	93	257.00	94	88
208.00	89	92	258.00	999	98
209.00	90	92	259.00	999	88
210.00	89	92	260.00	999	87
211.00	87	93	261.00	999	77
212.00	86	87	262.00	94	79
213.00	85	82	263.00	73	49
214.00	82	82	264.00	65	89
215.00	78	76	265.00	91	90
216.00	73	73	266.00	999	88
217.00	77	74	267.00	95	88
218.00	77	73	268.00	91	90
219.00	76	72	269.00	999	85
220.00	76	80	270.00	88	84
221.00	76	81	271.00	89	999
222.00	76	81	272.00	89	87
223.00	83	86	273.00	86	89
224.00	80	85	274.00	96	89
225.00	88	84	275.00	91	87
226.00	87	85	276.00	90	89
227.00	86	84	277.00	93	84
228.00	88	82	278.00	91	88
229.00	86	79	279.00	999	82
230.00	79	79	280.00	96	87
231.00	87	72	281.00	94	87
232.00	87	70	282.00	999	88
233.00	88	72	283.00	999	92
234.00	87	74	284.00	999	93
235.00	86	75	285.00	128	97
236.00	87	83	286.00	139	101
237.00	79	86	287.00	82	102
238.00	80	74	288.00	93	111
239.00	90	104	289.00	92	129
240.00	90	83	290.00	86	124
241.00	100	88	291.00	83	120
242.00	98	109	292.00	138	113
243.00	93	91	293.00	999	112
244.00	89	93	294.00	999	105
245.00	98	92	295.00	147	104
246.00	999	84	296.00	101	107
247.00	999	86	297.00	103	112
248.00	94	999	298.00	93	124
249.00	94	80	299.00	91	119
250.00	91	88	300.00	131	118

Note: Thickness = 999 implies waveforms cannot be processed

Table 3 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (386-based)

METRES	1	2	METRES	1	2
301.00	127 mm	122 mm	351.00	101 mm	92 mm
302.00	116	112	352.00	101	91
303.00	119	109	353.00	104	90
304.00	111	106	354.00	100	89
305.00	101	98	355.00	93	87
306.00	100	96	356.00	79	85
307.00	100	98	357.00	87	87
308.00	101	93	358.00	97	89
309.00	106	97	359.00	99	90
310.00	112	95	360.00	96	90
311.00	113	93	361.00	94	91
312.00	100	91	362.00	93	89
313.00	98	93	363.00	96	84
314.00	99	91	364.00	94	87
315.00	98	91	365.00	93	84
316.00	96	95	366.00	92	83
317.00	94	93	367.00	94	85
318.00	97	95	368.00	95	84
319.00	101	93	369.00	94	83
320.00	95	92	370.00	94	84
321.00	93	89	371.00	92	85
322.00	92	87	372.00	91	87
323.00	94	92	373.00	89	87
324.00	100	93	374.00	86	84
325.00	111	95	375.00	87	83
326.00	112	96	376.00	90	85
327.00	111	95	377.00	88	81
328.00	109	93	378.00	89	81
329.00	96	90	379.00	91	82
330.00	94	88	380.00	92	85
331.00	96	89	381.00	89	88
332.00	95	88	382.00	90	89
333.00	103	87	383.00	92	89
334.00	101	87	384.00	91	91
335.00	100	88	385.00	91	88
336.00	100	88	386.00	92	90
337.00	99	89	387.00	91	86
338.00	103	89	388.00	94	89
339.00	103	89	389.00	95	88
340.00	101	90	390.00	95	87
341.00	105	89	391.00	92	87
342.00	112	90	392.00	95	85
343.00	112	91	393.00	96	84
344.00	104	92	394.00	95	81
345.00	102	94	395.00	93	80
346.00	108	90	396.00	91	77
347.00	106	93	397.00	94	82
348.00	104	93	398.00	91	84
349.00	101	93	399.00	91	76
350.00	101	93	400.00	91	77

Table 3 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (386-based)

METRES	1	2	METRES	1	2
401.00	90 mm	77 mm	451.00	91 mm	92 mm
402.00	87	77	452.00	91	91
403.00	91	79	453.00	90	96
404.00	89	84	454.00	92	94
405.00	95	86	455.00	92	92
406.00	94	88	456.00	94	92
407.00	96	89	457.00	93	92
408.00	95	89	458.00	94	92
409.00	95	89	459.00	90	90
410.00	94	89	460.00	88	87
411.00	94	89	461.00	88	88
412.00	92	89	462.00	89	86
413.00	91	90	463.00	89	87
414.00	91	89	464.00	89	88
415.00	94	88	465.00	89	87
416.00	95	88	466.00	87	86
417.00	93	89	467.00	87	86
418.00	97	89	468.00	88	87
419.00	93	90	469.00	88	87
420.00	91	91	470.00	87	87
421.00	91	92	471.00	81	87
422.00	90	95	472.00	84	86
423.00	89	93	473.00	81	86
424.00	90	93	474.00	83	83
425.00	90	91	475.00	87	82
426.00	88	92	476.00	89	79
427.00	91	92	477.00	88	79
428.00	96	91	478.00	86	85
429.00	94	90	479.00	88	86
430.00	94	90	480.00	89	83
431.00	89	90	481.00	89	88
432.00	89	86	482.00	89	88
433.00	90	81	483.00	77	88
434.00	85	77	484.00	68	85
435.00	81	80	485.00	74	97
436.00	78	75	486.00	73	77
437.00	78	74	487.00	72	77
438.00	80	72	488.00	70	75
439.00	87	72	489.00	68	72
440.00	94	80	490.00	66	75
441.00	91	81	491.00	68	72
442.00	93	83	492.00	76	76
443.00	92	85	493.00	77	79
444.00	89	84	494.00	79	76
445.00	93	87	495.00	79	79
446.00	94	88	496.00	80	77
447.00	97	88	497.00	81	76
448.00	96	89	498.00	78	79
449.00	93	91	499.00	84	80
450.00	93	93	500.00	90	82

Table 3 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (386-based)

METRES	1	2	METRES	1	2
501.00	86 mm	86 mm	551.00	94 mm	79 mm
502.00	88	88	552.00	89	83
503.00	91	89	553.00	91	83
504.00	89	90	554.00	90	79
505.00	91	85	555.00	87	79
506.00	87	84	556.00	86	81
507.00	85	85	557.00	86	83
508.00	82	88	558.00	84	86
509.00	83	80	559.00	85	83
510.00	85	75	560.00	82	80
511.00	81	78	561.00	83	81
512.00	84	78	562.00	78	80
513.00	98	77	563.00	75	79
514.00	86	71	564.00	72	82
515.00	79	68	565.00	74	81
516.00	78	71	566.00	76	82
517.00	74	66	567.00	75	82
518.00	77	69	568.00	74	77
519.00	76	70	569.00	77	78
520.00	77	71	570.00	78	75
521.00	79	76	571.00	81	76
522.00	77	74	572.00	73	76
523.00	77	74	573.00	66	74
524.00	77	74	574.00	113	74
525.00	76	75	575.00	109	75
526.00	77	76	576.00	65	79
527.00	76	73	577.00	999	78
528.00	74	83	578.00	61	70
529.00	75	74	579.00	61	76
530.00	73	72	580.00	109	78
531.00	75	72	581.00	114	76
532.00	72	73	582.00	66	82
533.00	70	73	583.00	65	76
534.00	73	73	584.00	67	68
535.00	72	75	585.00	72	69
536.00	76	70	586.00	87	79
537.00	76	75	587.00	90	85
538.00	77	72	588.00	89	91
539.00	78	72	589.00	91	93
540.00	77	73	590.00	92	93
541.00	81	72	591.00	93	90
542.00	85	74	592.00	91	91
543.00	85	79	593.00	90	90
544.00	87	75	594.00	92	95
545.00	86	73	595.00	94	99
546.00	88	74	596.00	96	105
547.00	87	78	597.00	99	105
548.00	89	75	598.00	98	99
549.00	93	75	599.00	95	99
550.00	90	78	600.00	89	95

Table 3 (continued)/ Hwy. 7 at Dufferin Street - Computed Asphalt Thickness (386-based)

```
 [ OVERALL SUMMARY ]
Thornhill at Hwy 7/Dufferin, 2 lines (386)
DATE =  3  6.1991          TIME = 11:12:51:28
[ FLAT PLATE AMPLITUDE ]  =   9.157717 v
[ FIFTH WHEEL ]           =      .1000 m
[ Pavement Range ]        =   600.0000 m
[ OUTPUT FORMAT ] every   =     1.0000 m
[ ASPHALT core sample ]   = 130.0 mm

[ AVERAGE DIELECTRIC CONSTANT OF ASPHALT ]
             1      2
-----------------------------------------------------------------------------
            9.83   10.43

 [ AVERAGE ASPHALT THICKNESS ]
              1       2
-----------------------------------------------------------------------------
millimetres     93      91


[ OVERALL AVERAGE ]
[ dielectric constant of aspahlt ] =  10.128640
[ asphalt thickness (mm) ]         =   92
```

Table 4/ 10 cm Fifth Wheel Pulses at Variable Van Speed

```
 van speed             =    5.00 km/h             =  138.89 cm/sec
 1 second duration     =   50    radar waveforms
 1 cm fifth wheel      =     .36 radar waveforms =    7.20 ms
 half fifth wheel      =    3.60 ms
 1 radar waveform      =    2.78 cm               =   20.00 ms
 10.00 cm pusle        =    3.60 waveforms        =   72.00 ms
 120.00 cm  distance   =  864.00 ms               =   12     fifth wheel pulses

cm  10  Rise=  64.80 Fall=  68.40  iON=  60  trigB =  80 trigE= 100  flag=1
cm  20  Rise= 136.80 Fall= 140.40  iON= 140  trigB = 140 trigE= 160  flag=1
cm  30  Rise= 208.80 Fall= 212.40  iON= 200  trigB = 220 trigE= 240  flag=1
cm  40  Rise= 280.80 Fall= 284.40  iON= 280  trigB = 300 trigE= 320  flag=1
cm  50  Rise= 352.80 Fall= 356.40  iON= 360  trigB = 360 trigE= 380  flag=1
cm  60  Rise= 424.80 Fall= 428.40  iON= 420  trigB = 440 trigE= 460  flag=1
cm  70  Rise= 496.80 Fall= 500.40  iON= 500  trigB = 500 trigE= 520  flag=1
cm  80  Rise= 568.80 Fall= 572.40  iON= 560  trigB = 580 trigE= 600  flag=1
cm  90  Rise= 640.80 Fall= 644.40  iON= 640  trigB = 660 trigE= 680  flag=1
cm 100  Rise= 712.80 Fall= 716.40  iON= 720  trigB = 720 trigE= 740  flag=1
cm 110  Rise= 784.80 Fall= 788.40  iON= 780  trigB = 800 trigE= 820  flag=1
cm 120  Rise= 856.80 Fall= 860.40  iON= 860  trigB = 860 trigE= 880  flag=1

 van speed             =   10.00 km/h             =  277.78 cm/sec
 1 second duration     =   50    radar waveforms
 1 cm fifth wheel      =     .18 radar waveforms =    3.60 ms
 half fifth wheel      =    1.80 ms
 1 radar waveform      =    5.56 cm               =   20.00 ms
 10.00 cm pusle        =    1.80 waveforms        =   36.00 ms
 120.00 cm  distance   =  432.00 ms               =   12     fifth wheel pulses

cm  10  Rise=  32.40 Fall=  34.20  iON=  40  trigB =  40 trigE=  60  flag=1
cm  20  Rise=  68.40 Fall=  70.20  iON=  60  trigB =  80 trigE= 100  flag=1
cm  30  Rise= 104.40 Fall= 106.20  iON= 100  trigB = 120 trigE= 140  flag=1
cm  40  Rise= 140.40 Fall= 142.20  iON= 140  trigB = 160 trigE= 180  flag=1
cm  50  Rise= 176.40 Fall= 178.20  iON=   0  trigB = 160 trigE= 180  flag=0
cm  60  Rise= 212.40 Fall= 214.20  iON= 220  trigB = 220 trigE= 240  flag=1
cm  70  Rise= 248.40 Fall= 250.20  iON= 240  trigB = 260 trigE= 280  flag=1
cm  80  Rise= 284.40 Fall= 286.20  iON= 280  trigB = 300 trigE= 320  flag=1
cm  90  Rise= 320.40 Fall= 322.20  iON= 320  trigB = 340 trigE= 360  flag=1
cm 100  Rise= 356.40 Fall= 358.20  iON=   0  trigB = 340 trigE= 360  flag=0
cm 110  Rise= 392.40 Fall= 394.20  iON= 400  trigB = 400 trigE= 420  flag=1
cm 120  Rise= 428.40 Fall= 430.20  iON= 420  trigB = 440 trigE= 460  flag=1

 van speed             =   15.00 km/h             =  416.67 cm/sec
 1 second duration     =   50    radar waveforms
 1 cm fifth wheel      =     .12 radar waveforms =    2.40 ms
 half fifth wheel      =    1.20 ms
 1 radar waveform      =    8.33 cm               =   20.00 ms
 10.00 cm pusle        =    1.20 waveforms        =   24.00 ms
 120.00 cm  distance   =  288.00 ms               =   12     fifth wheel pulses

cm  10  Rise=  21.60 Fall=  22.80  iON=  20  trigB =  40 trigE=  60  flag=1
cm  20  Rise=  45.60 Fall=  46.80  iON=   0  trigB =  40 trigE=  60  flag=0
cm  30  Rise=  69.60 Fall=  70.80  iON=  60  trigB =  80 trigE= 100  flag=1
cm  40  Rise=  93.60 Fall=  94.80  iON=   0  trigB =  80 trigE= 100  flag=0
cm  50  Rise= 117.60 Fall= 118.80  iON= 120  trigB = 120 trigE= 140  flag=1
cm  60  Rise= 141.60 Fall= 142.80  iON= 140  trigB = 160 trigE= 180  flag=1
cm  70  Rise= 165.60 Fall= 166.80  iON=   0  trigB = 160 trigE= 180  flag=0
cm  80  Rise= 189.60 Fall= 190.80  iON= 180  trigB = 200 trigE= 220  flag=1
cm  90  Rise= 213.60 Fall= 214.80  iON=   0  trigB = 200 trigE= 220  flag=0
cm 100  Rise= 237.60 Fall= 238.80  iON= 240  trigB = 240 trigE= 260  flag=1
cm 110  Rise= 261.60 Fall= 262.80  iON= 260  trigB = 280 trigE= 300  flag=1
cm 120  Rise= 285.60 Fall= 286.80  iON=   0  trigB = 280 trigE= 300  flag=0
```

Table 4 (continued)/ 10 cm Fifth Wheel Pulses at Variable Van Speed

```
 van speed             =    20.00 km/h              =  555.56 cm/sec
 1 second duration     =   50     radar waveforms
 1 cm fifth wheel      =      .09 radar waveforms =    1.80 ms
 half fifth wheel      =      .90 ms
 1 radar waveform      =   11.11 cm                 =  20.00 ms
 10.00 cm pusle        =      .90 waveforms         =  18.00 ms
 120.00 cm  distance   =  216.00 ms                 =  12     fifth wheel pulses

cm  10  Rise=  16.20 Fall=  17.10  iON=   0  trigB =   0 trigE=   0  flag=0
cm  20  Rise=  34.20 Fall=  35.10  iON=  40  trigB =  40 trigE=  60  flag=1
cm  30  Rise=  52.20 Fall=  53.10  iON=   0  trigB =  40 trigE=  60  flag=0
cm  40  Rise=  70.20 Fall=  71.10  iON=  80  trigB =  80 trigE= 100  flag=1
cm  50  Rise=  88.20 Fall=  89.10  iON=   0  trigB =  80 trigE= 100  flag=0
cm  60  Rise= 106.20 Fall= 107.10  iON= 100  trigB = 120 trigE= 140  flag=1
cm  70  Rise= 124.20 Fall= 125.10  iON=   0  trigB = 120 trigE= 140  flag=0
cm  80  Rise= 142.20 Fall= 143.10  iON= 140  trigB = 160 trigE= 180  flag=1
cm  90  Rise= 160.20 Fall= 161.10  iON=   0  trigB = 160 trigE= 180  flag=0
cm 100  Rise= 178.20 Fall= 179.10  iON=   0  trigB = 160 trigE= 180  flag=0
cm 110  Rise= 196.20 Fall= 197.10  iON= 200  trigB = 200 trigE= 220  flag=1
cm 120  Rise= 214.20 Fall= 215.10  iON=   0  trigB = 200 trigE= 220  flag=0

 van speed             =    25.00 km/h              =  694.44 cm/sec
 1 second duration     =   50     radar waveforms
 1 cm fifth wheel      =      .07 radar waveforms =    1.44 ms
 half fifth wheel      =      .72 ms
 1 radar waveform      =   13.89 cm                 =  20.00 ms
 10.00 cm pusle        =      .72 waveforms         =  14.40 ms
 120.00 cm  distance   =  172.80 ms                 =  12     fifth wheel pulses

cm  10  Rise=  12.96 Fall=  13.68  iON=   0  trigB =   0 trigE=   0  flag=0
cm  20  Rise=  27.36 Fall=  28.08  iON=  20  trigB =  40 trigE=  60  flag=1
cm  30  Rise=  41.76 Fall=  42.48  iON=   0  trigB =  40 trigE=  60  flag=0
cm  40  Rise=  56.16 Fall=  56.88  iON=   0  trigB =  40 trigE=  60  flag=0
cm  50  Rise=  70.56 Fall=  71.28  iON=  80  trigB =  80 trigE= 100  flag=1
cm  60  Rise=  84.96 Fall=  85.68  iON=   0  trigB =  80 trigE= 100  flag=0
cm  70  Rise=  99.36 Fall= 100.08  iON=   0  trigB =  80 trigE= 100  flag=0
cm  80  Rise= 113.76 Fall= 114.48  iON= 120  trigB = 120 trigE= 140  flag=1
cm  90  Rise= 128.16 Fall= 128.88  iON=   0  trigB = 120 trigE= 140  flag=0
cm 100  Rise= 142.56 Fall= 143.28  iON= 140  trigB = 160 trigE= 180  flag=1
cm 110  Rise= 156.96 Fall= 157.68  iON=   0  trigB = 160 trigE= 180  flag=0
cm 120  Rise= 171.36 Fall= 172.08  iON=   0  trigB = 160 trigE= 180  flag=0

 van speed             =    30.00 km/h              =  833.33 cm/sec
 1 second duration     =   50     radar waveforms
 1 cm fifth wheel      =      .06 radar waveforms =    1.20 ms
 half fifth wheel      =      .60 ms
 1 radar waveform      =   16.67 cm                 =  20.00 ms
 10.00 cm pusle        =      .60 waveforms         =  12.40 ms
 120.00 cm  distance   =  144.00 ms                 =  12     fifth wheel pulses

cm  10  Rise=  10.80 Fall=  11.40  iON=   0  trigB =   0 trigE=   0  flag=0
cm  20  Rise=  22.80 Fall=  23.40  iON=  20  trigB =  40 trigE=  60  flag=1
cm  30  Rise=  34.80 Fall=  35.40  iON=   0  trigB =  40 trigE=  60  flag=0
cm  40  Rise=  46.80 Fall=  47.40  iON=   0  trigB =  40 trigE=  60  flag=0
cm  50  Rise=  58.80 Fall=  59.40  iON=   0  trigB =  40 trigE=  60  flag=0
cm  60  Rise=  70.80 Fall=  71.40  iON=  80  trigB =  80 trigE= 100  flag=1
cm  70  Rise=  82.80 Fall=  83.40  iON=   0  trigB =  80 trigE= 100  flag=0
cm  80  Rise=  94.80 Fall=  95.40  iON=   0  trigB =  80 trigE= 100  flag=0
cm  90  Rise= 106.80 Fall= 107.40  iON= 100  trigB = 120 trigE= 140  flag=1
cm 100  Rise= 118.80 Fall= 119.40  iON=   0  trigB = 120 trigE= 140  flag=0
cm 110  Rise= 130.80 Fall= 131.40  iON=   0  trigB = 120 trigE= 140  flag=0
cm 120  Rise= 142.80 Fall= 143.40  iON= 140  trigB = 160 trigE= 180  flag=1
```

Table 5/ Fifth Wheel Pulses and Variable Van Speed

```
 van speed           =    10.00 km/h            =  277.78 cm/sec
 1 second duration   =   50     radar waveforms
 1 cm fifth wheel    =      .18 radar waveforms =   3.60 ms
 half fifth wheel    =     1.80 ms
 1 radar waveform    =     5.56 cm              =   20.00 ms
 20.00 cm pusle      =     3.60 waveforms       =   72.40 ms
 200.00 cm  distance =   720.00 ms              =   10    fifth wheel pulses

cm  20  Rise=  68.40 Fall=  70.20  iON=  60  trigB =  80 trigE= 100  flag=1
cm  40  Rise= 140.40 Fall= 142.20  iON= 140  trigB = 160 trigE= 180  flag=1
cm  60  Rise= 212.40 Fall= 214.20  iON= 220  trigB = 220 trigE= 240  flag=1
cm  80  Rise= 284.40 Fall= 286.20  iON= 280  trigB = 300 trigE= 320  flag=1
cm 100  Rise= 356.40 Fall= 358.20  iON= 360  trigB = 360 trigE= 380  flag=1
cm 120  Rise= 428.40 Fall= 430.20  iON= 420  trigB = 440 trigE= 460  flag=1
cm 140  Rise= 500.40 Fall= 502.20  iON= 500  trigB = 520 trigE= 540  flag=1
cm 160  Rise= 572.40 Fall= 574.20  iON= 580  trigB = 580 trigE= 600  flag=1
cm 180  Rise= 644.40 Fall= 646.20  iON= 640  trigB = 660 trigE= 680  flag=1
cm 200  Rise= 716.40 Fall= 718.20  iON= 720  trigB = 720 trigE= 740  flag=1

 van speed           =    20.00 km/h            =  555.56 cm/sec
 1 second duration   =   50     radar waveforms
 1 cm fifth wheel    =      .09 radar waveforms =   1.80 ms
 half fifth wheel    =      .90 ms
 1 radar waveform    =    11.11 cm              =   20.00 ms
 20.00 cm pusle      =     1.80 waveforms       =   36.00 ms
 200.00 cm  distance =   360.00 ms              =   10    fifth wheel pulses

cm  20  Rise=  34.20 Fall=  35.10  iON=  40  trigB =  40 trigE=  60  flag=1
cm  40  Rise=  70.20 Fall=  71.10  iON=  80  trigB =  80 trigE= 100  flag=1
cm  60  Rise= 106.20 Fall= 107.10  iON= 100  trigB = 120 trigE= 140  flag=1
cm  80  Rise= 142.20 Fall= 143.10  iON= 140  trigB = 160 trigE= 180  flag=1
cm 100  Rise= 178.20 Fall= 179.10  iON=   0  trigB = 160 trigE= 180  flag=0
cm 120  Rise= 214.20 Fall= 215.10  iON= 220  trigB = 220 trigE= 240  flag=1
cm 140  Rise= 250.20 Fall= 251.10  iON= 260  trigB = 260 trigE= 280  flag=1
cm 160  Rise= 286.20 Fall= 287.10  iON= 280  trigB = 300 trigE= 320  flag=1
cm 180  Rise= 322.20 Fall= 323.10  iON= 320  trigB = 340 trigE= 360  flag=1
cm 200  Rise= 358.20 Fall= 359.10  iON=   0  trigB = 340 trigE= 360  flag=0

 van speed           =    20.00 km/h            =  555.56 cm/sec
 1 second duration   =   50     radar waveforms
 1 cm fifth wheel    =      .09 radar waveforms =   1.80 ms
 half fifth wheel    =      .90 ms
 1 radar waveform    =    11.11 cm              =   20.00 ms
 50.00 cm pusle      =     4.50 waveforms       =   90.00 ms
 800.00 cm  distance =  1440.00 ms              =   16    fifth wheel pulses

cm  50  Rise=  88.20 Fall=  89.10  iON=  80  trigB = 100 trigE= 120  flag=1
cm 100  Rise= 178.20 Fall= 179.10  iON= 180  trigB = 180 trigE= 200  flag=1
cm 150  Rise= 268.20 Fall= 269.10  iON= 260  trigB = 280 trigE= 300  flag=1
cm 200  Rise= 358.20 Fall= 359.10  iON= 360  trigB = 360 trigE= 380  flag=1
cm 250  Rise= 448.20 Fall= 449.10  iON= 440  trigB = 460 trigE= 480  flag=1
cm 300  Rise= 538.20 Fall= 539.10  iON= 540  trigB = 540 trigE= 560  flag=1
cm 350  Rise= 628.20 Fall= 629.10  iON= 620  trigB = 640 trigE= 660  flag=1
cm 400  Rise= 718.20 Fall= 719.10  iON= 720  trigB = 720 trigE= 740  flag=1
cm 450  Rise= 808.20 Fall= 809.10  iON= 800  trigB = 820 trigE= 840  flag=1
cm 500  Rise= 898.20 Fall= 899.10  iON= 900  trigB = 900 trigE= 920  flag=1
cm 550  Rise= 988.20 Fall= 989.10  iON= 980  trigB =1000 trigE=1020  flag=1
cm 600  Rise=1078.20 Fall=1079.10  iON=1080  trigB =1080 trigE=1100  flag=1
cm 650  Rise=1168.20 Fall=1169.10  iON=1160  trigB =1180 trigE=1200  flag=1
cm 700  Rise=1258.20 Fall=1259.10  iON=1260  trigB =1260 trigE=1280  flag=1
cm 750  Rise=1348.20 Fall=1349.10  iON=1340  trigB =1360 trigE=1380  flag=1
cm 800  Rise=1438.20 Fall=1439.10  iON=1440  trigB =1440 trigE=1460  flag=1
```

Table 6/ Hwy. 12 at 400 (Cold Water) - Computed Asphalt Thickness

```
 [ SUMMARY ]

DATE =  3  6.1991           TIME = 11:19:35: 3

Cold Water at Hwy 12/400, 1 line

AVERAGE Bridge Length =     457.00 metres     NUMBER of LINES processed =  1

   METRES      1                 METRES      1
-----------------------------------------------------------------------------
       1.00   100 mm              51.00     99 mm
       2.00   105                 52.00     99
       3.00    95                 53.00     90
       4.00    91                 54.00     88
       5.00    96                 55.00     90
       6.00    96                 56.00     98
       7.00    93                 57.00    103
       8.00    96                 58.00     91
       9.00    94                 59.00     91
      10.00    94                 60.00     97
      11.00   100                 61.00     93
      12.00    93                 62.00     94
      13.00    92                 63.00     94
      14.00    94                 64.00    104
      15.00    92                 65.00     89
      16.00   103                 66.00     93
      17.00    91                 67.00     94
      18.00    90                 68.00     88
      19.00    97                 69.00     88
      20.00    92                 70.00    153
      21.00    97                 71.00    152
      22.00    90                 72.00    152
      23.00    89                 73.00    152
      24.00    89                 74.00    150
      25.00    91                 75.00    147
      26.00    95                 76.00    137
      27.00    90                 77.00    146
      28.00   101                 78.00    148
      29.00   130                 79.00    144
      30.00   148                 80.00    143
      31.00    90                 81.00    147
      32.00    96                 82.00    148
      33.00    90                 83.00    151
      34.00    91                 84.00    101
      35.00    89                 85.00    120
      36.00    90                 86.00    146
      37.00    89                 87.00    149
      38.00    92                 88.00    102
      39.00    98                 89.00    102
      40.00    90                 90.00     90
      41.00    92                 91.00     88
      42.00    97                 92.00     91
      43.00   100                 93.00     95
      44.00    92                 94.00    100
      45.00    91                 95.00    107
      46.00    91                 96.00    115
      47.00    97                 97.00     98
      48.00    98                 98.00     93
      49.00    91                 99.00    102
      50.00    92                100.00    129
```

Table 6 (continued)/ Hwy. 12 at 400 (Cold Water) - Computed Asphalt Thickness

METRES	1	METRES	1
101.00	138 mm	151.00	94 mm
102.00	97	152.00	96
103.00	97	153.00	90
104.00	100	154.00	98
105.00	96	155.00	99
106.00	100	156.00	92
107.00	99	157.00	93
108.00	100	158.00	102
109.00	101	159.00	98
110.00	113	160.00	104
111.00	88	161.00	98
112.00	98	162.00	101
113.00	104	163.00	115
114.00	105	164.00	114
115.00	103	165.00	111
116.00	101	166.00	114
117.00	99	167.00	104
118.00	92	168.00	119
119.00	94	169.00	122
120.00	93	170.00	102
121.00	90	171.00	107
122.00	92	172.00	103
123.00	93	173.00	114
124.00	96	174.00	116
125.00	94	175.00	117
126.00	104	176.00	113
127.00	102	177.00	91
128.00	102	178.00	88
129.00	134	179.00	93
130.00	98	180.00	125
131.00	117	181.00	125
132.00	131	182.00	123
133.00	129	183.00	117
134.00	93	184.00	120
135.00	123	185.00	124
136.00	121	186.00	126
137.00	115	187.00	120
138.00	118	188.00	119
139.00	111	189.00	122
140.00	112	190.00	117
141.00	117	191.00	118
142.00	121	192.00	121
143.00	110	193.00	123
144.00	108	194.00	120
145.00	114	195.00	122
146.00	113	196.00	121
147.00	103	197.00	121
148.00	97	198.00	118
149.00	89	199.00	119
150.00	107	200.00	122

Table 6 (continued)/ Hwy. 12 at 400 (Cold Water) - Computed Asphalt Thickness

METRES	1	METRES	1
201.00	117 mm	251.00	111 mm
202.00	120	252.00	114
203.00	128	253.00	107
204.00	119	254.00	108
205.00	123	255.00	107
206.00	119	256.00	115
207.00	116	257.00	113
208.00	114	258.00	114
209.00	116	259.00	110
210.00	112	260.00	113
211.00	124	261.00	118
212.00	114	262.00	117
213.00	117	263.00	128
214.00	114	264.00	115
215.00	115	265.00	116
216.00	110	266.00	108
217.00	115	267.00	114
218.00	111	268.00	110
219.00	112	269.00	105
220.00	114	270.00	111
221.00	115	271.00	111
222.00	117	272.00	114
223.00	119	273.00	115
224.00	119	274.00	111
225.00	117	275.00	115
226.00	123	276.00	107
227.00	122	277.00	107
228.00	118	278.00	120
229.00	116	279.00	112
230.00	118	280.00	110
231.00	119	281.00	107
232.00	117	282.00	116
233.00	115	283.00	112
234.00	113	284.00	108
235.00	109	285.00	119
236.00	109	286.00	118
237.00	107	287.00	115
238.00	107	288.00	109
239.00	110	289.00	103
240.00	105	290.00	106
241.00	103	291.00	107
242.00	106	292.00	116
243.00	111	293.00	115
244.00	98	294.00	122
245.00	105	295.00	116
246.00	106	296.00	123
247.00	109	297.00	115
248.00	118	298.00	117
249.00	110	299.00	117
250.00	109	300.00	117

Table 6 (continued)/ Hwy. 12 at 400 (Cold Water) - Computed Asphalt Thickness

METRES	1	METRES	1
301.00	117 mm	351.00	120 mm
302.00	121	352.00	119
303.00	119	353.00	117
304.00	118	354.00	131
305.00	118	355.00	127
306.00	119	356.00	128
307.00	116	357.00	122
308.00	111	358.00	120
309.00	116	359.00	115
310.00	118	360.00	118
311.00	118	361.00	118
312.00	116	362.00	118
313.00	117	363.00	119
314.00	117	364.00	122
315.00	116	365.00	120
316.00	116	366.00	123
317.00	114	367.00	121
318.00	114	368.00	121
319.00	112	369.00	122
320.00	118	370.00	120
321.00	119	371.00	127
322.00	112	372.00	122
323.00	129	373.00	122
324.00	118	374.00	125
325.00	122	375.00	125
326.00	118	376.00	121
327.00	116	377.00	127
328.00	117	378.00	124
329.00	122	379.00	131
330.00	121	380.00	128
331.00	114	381.00	129
332.00	112	382.00	131
333.00	115	383.00	128
334.00	117	384.00	129
335.00	116	385.00	128
336.00	115	386.00	125
337.00	103	387.00	123
338.00	116	388.00	126
339.00	114	389.00	123
340.00	115	390.00	123
341.00	115	391.00	117
342.00	110	392.00	117
343.00	120	393.00	116
344.00	118	394.00	114
345.00	117	395.00	116
346.00	114	396.00	112
347.00	113	397.00	114
348.00	115	398.00	114
349.00	113	399.00	115
350.00	117	400.00	115

Table 6 (continued)/ Hwy. 12 at 400 (Cold Water) - Computed Asphalt Thickness

METRES	1
401.00	117 mm
402.00	115
403.00	117
404.00	116
405.00	119
406.00	113
407.00	113
408.00	107
409.00	113
410.00	112
411.00	113
412.00	119
413.00	110
414.00	108
415.00	112
416.00	106
417.00	102
418.00	107
419.00	107
420.00	110
421.00	106
422.00	109
423.00	107
424.00	106
425.00	104
426.00	108
427.00	105
428.00	115
429.00	116
430.00	113
431.00	110
432.00	119
433.00	113
434.00	116
435.00	116
436.00	116
437.00	117
438.00	116
439.00	107
440.00	120
441.00	120
442.00	117
443.00	105
444.00	101
445.00	97
446.00	102
447.00	120
448.00	115
449.00	91
450.00	97
451.00	106 mm
452.00	109
453.00	116
454.00	111
455.00	116
456.00	115
457.00	116

Table 6 (continued)/ Hwy. 12 at 400 (Cold Water) - Computed Asphalt Thickness

```
  [ OVERALL SUMMARY ]
 Cold Water at Hwy 12/400, 1 line
 DATE =  3  6.1991          TIME = 11:19:36:35
 [ FLAT PLATE AMPLITUDE ]  =   9.378243 v
 [ FIFTH WHEEL ]           =      .1000 m
 [ Pavement Range ]        =   457.0000 m
 [ OUTPUT FORMAT ] every   =     1.0000 m
 [ ASPHALT core sample ]   = 120.0 mm

 [ AVERAGE DIELECTRIC CONSTANT OF ASPHALT ]
                 1
-----------------------------------------------------------------------------
                5.69

  [ AVERAGE ASPHALT THICKNESS ]
                1
-----------------------------------------------------------------------------
millimetres    111

 [ OVERALL AVERAGE ]
 [ dielectric constant of aspahlt ] =   5.689449
 [ asphalt thickness (mm) ]         =  111
```

Table 7/ Crack Locations and Status

	Crack Locations		Status
1.	13 m	centre line	Sealed, 40 x 10 mm rout
2.	50 m	centre line	Sealed, 40 x 10 mm rout
3.	59 m	centre line	New
4.	88 m	centre line	New
5.	93 m	centre line	Sealed, 40 x 10 mm rout
6.	189 m	centre line	Sealed, 19 x 19 mm rout
7.	235 m	centre line	Sealed, 19 x 19 mm rout
8.	255 m	centre line	New
9.	274 m	centre line	Sealed, 19 x 19 mm rout
10.	290 m	edge	New
11.	316 m	wheel path	Old
12.	328 m	wheel path	New
13.	346 m	centre line	Old
14.	352 m	center line	New
15.	371 m	edge	Old
16.	445 m	edge	Old

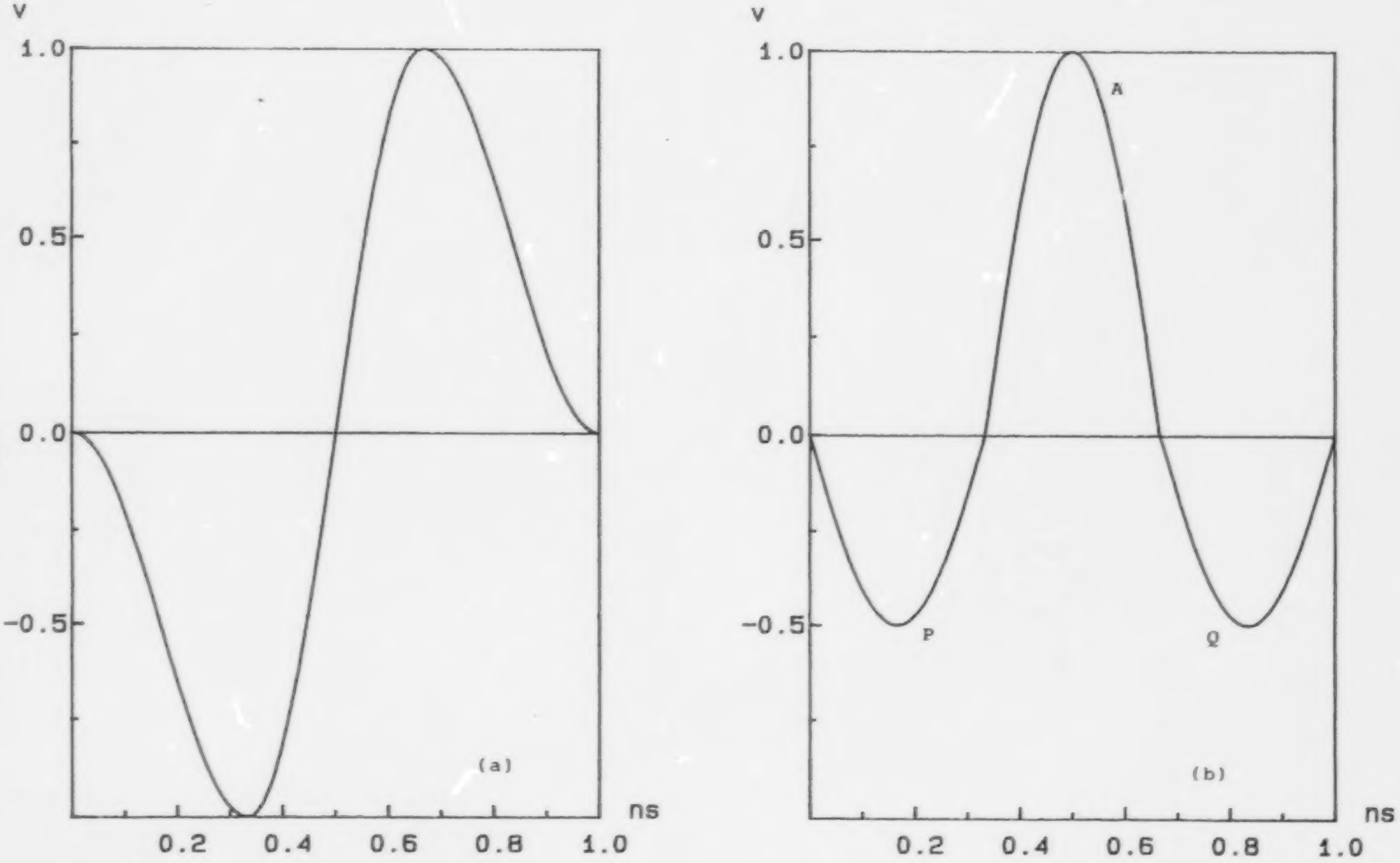


Fig 1: Simulated Impulse Radar Waveform
(a) A monocycle waveform, (b) Ideal symmetric impulse response.

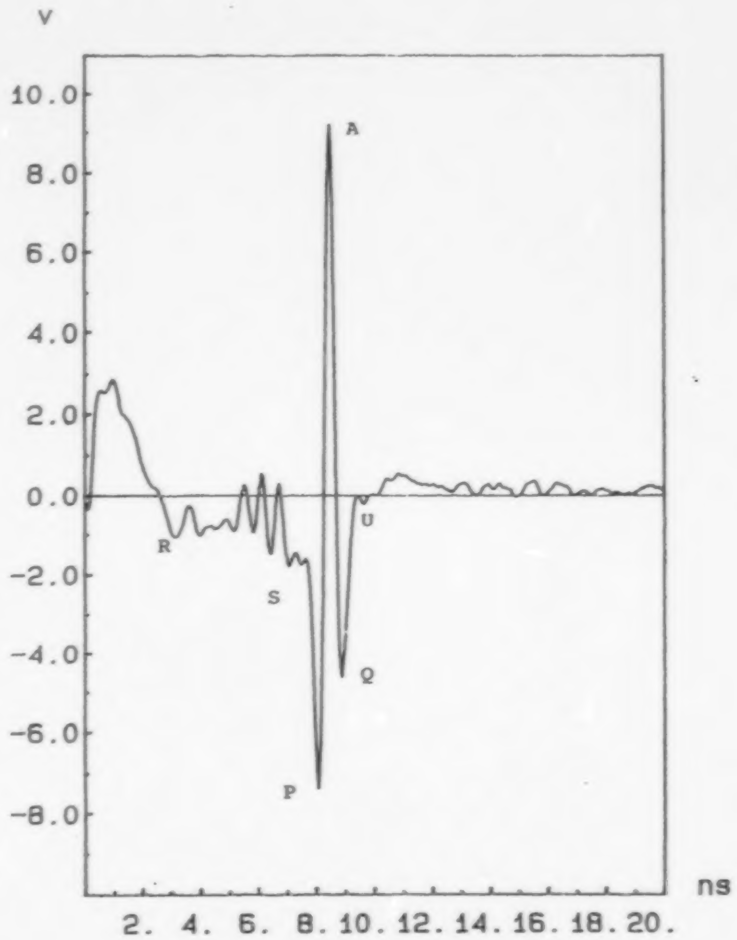


Fig 2: Actual transmitted waveform.

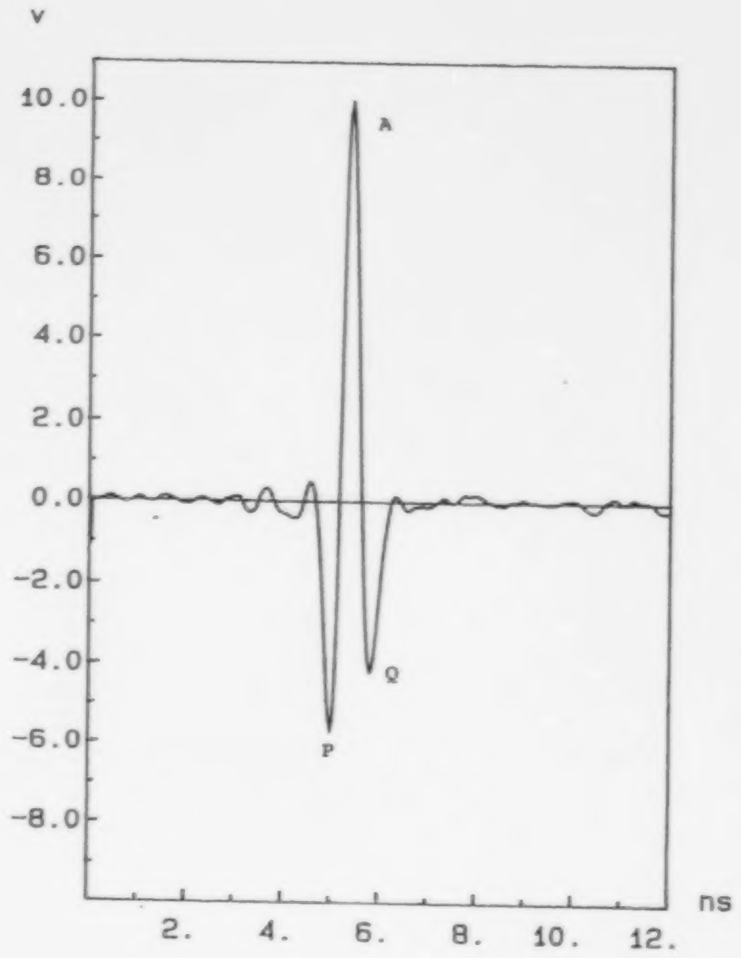


Fig 3: Corrected transmitted waveform.

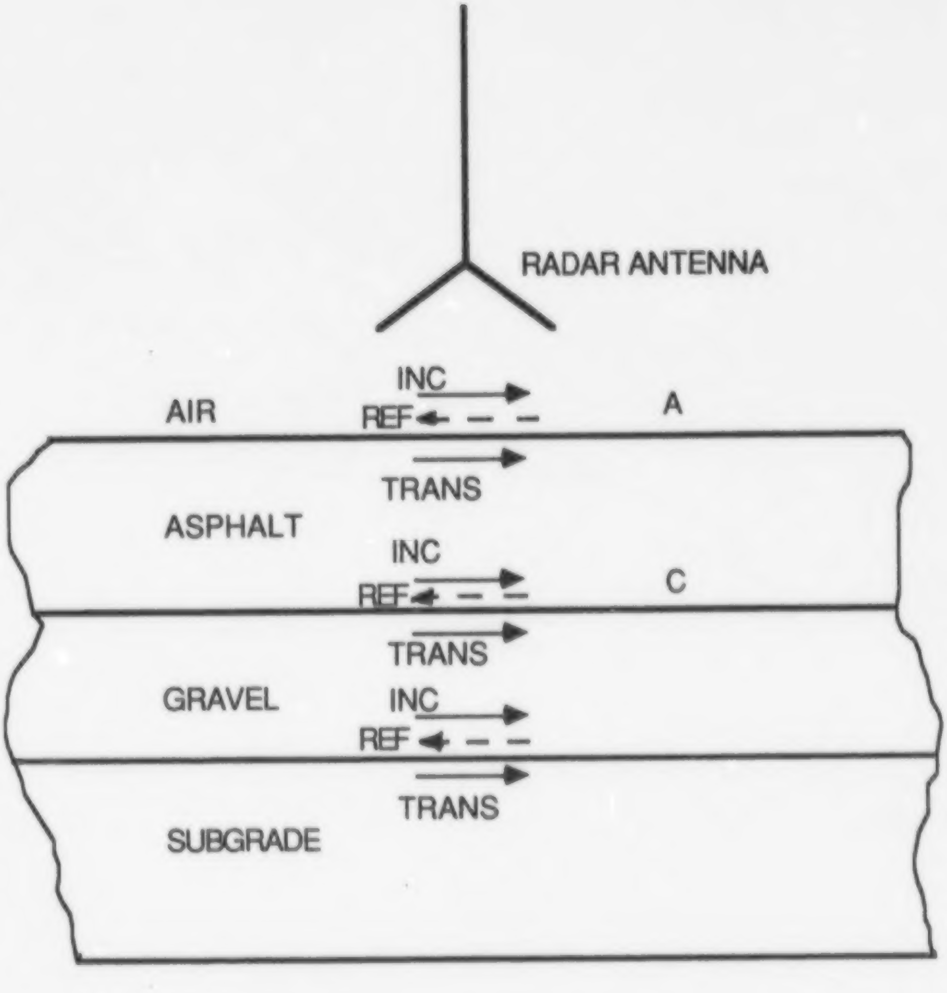

RADAR ANTENNA
INC
AIR
REF
A
TRANS
ASPHALT
INC
REF
C
TRANS
GRAVEL
INC
REF
TRANS
SUBGRADE

Fig 4: Pavement cross-section showing transmission through and reflections from the different layers.

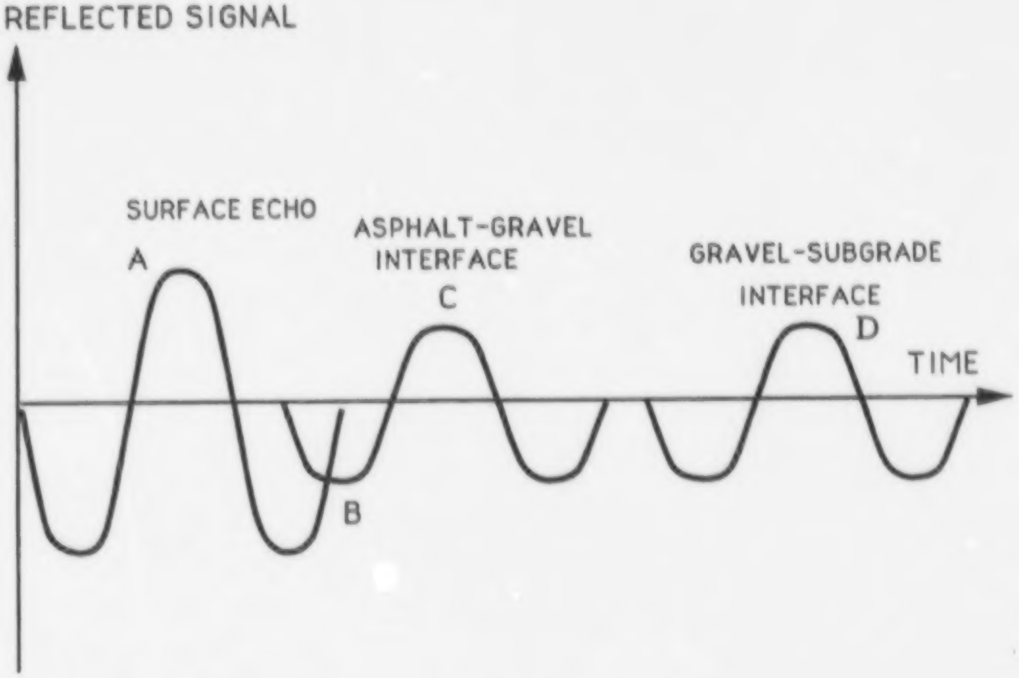

REFLECTED SIGNAL
SURFACE ECHO
A
ASPHALT-GRAVEL
INTERFACE
C
GRAVEL-SUBGRADE
INTERFACE
D
TIME
B

Fig 5: Expected reflections from undamaged pavement structure.

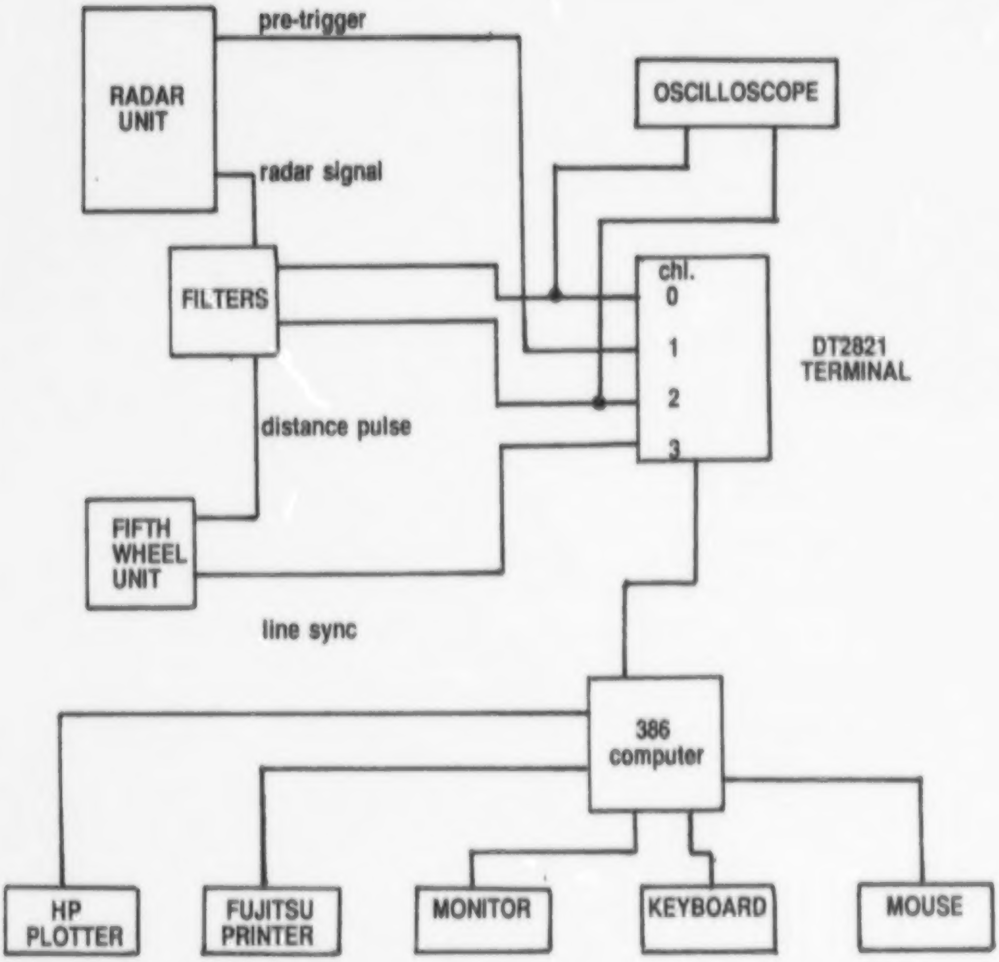

pre-trigger
RADAR UNIT
OSCILLOSCOPE
radar signal
FILTERS
chl.
0
1
2
3
DT2821 TERMINAL
distance pulse
FIFTH WHEEL UNIT
line sync
386 computer
HP PLOTTER
FUJITSU PRINTER
MONITOR
KEYBOARD
MOUSE

Figure 6: System Configuration of the 386-Based DART.

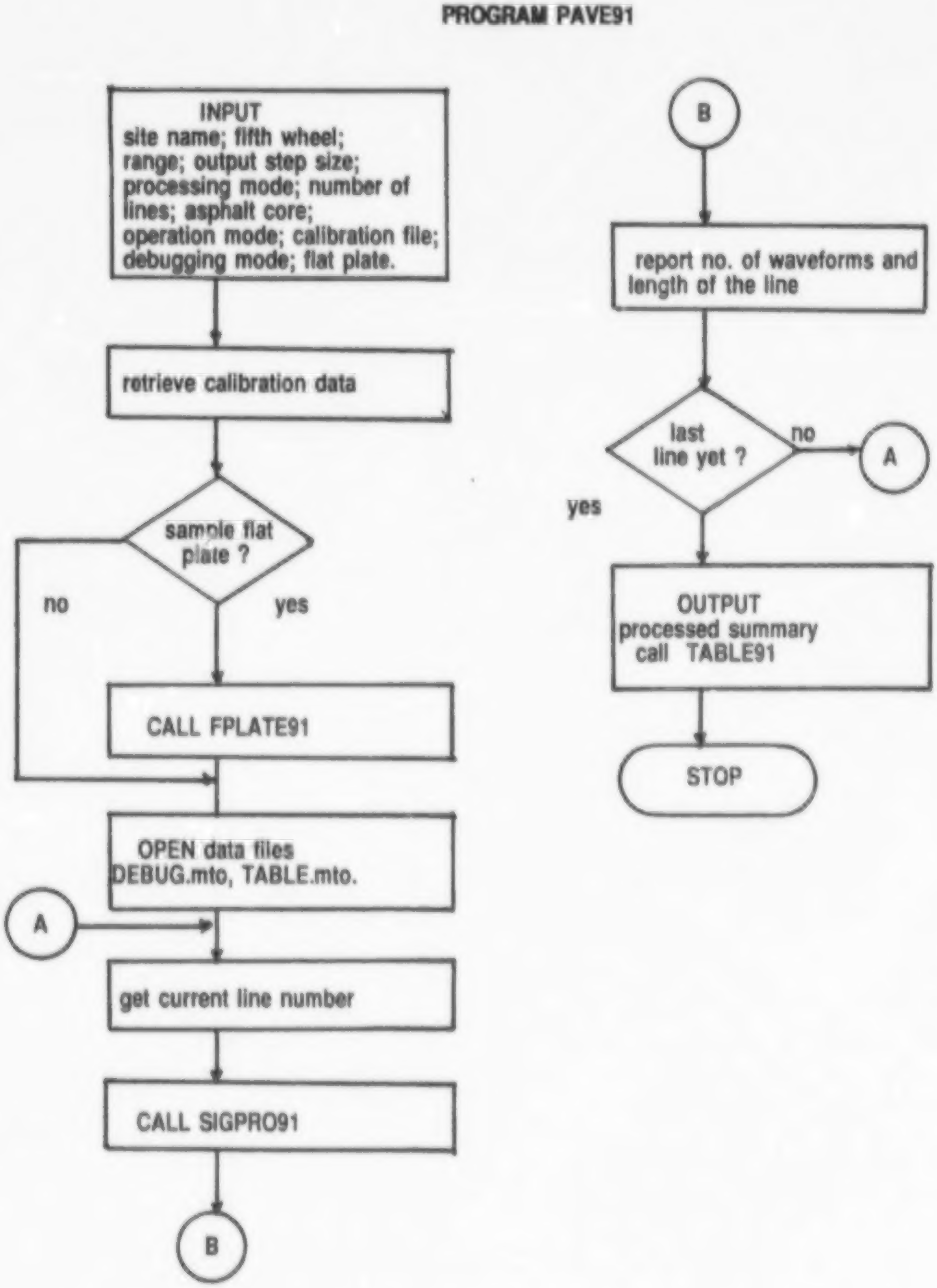

PROGRAM PAVE91
INPUT
site name; fifth wheel;
range; output step size;
processing mode; number of
lines; asphalt core;
operation mode; calibration file;
debugging mode; flat plate.
retrieve calibration data
sample flat plate ?
no
yes
CALL FPLATE91
OPEN data files
DEBUG.mto, TABLE.mto.
A
get current line number
CALL SIGPRO91
B
B
report no. of waveforms and
length of the line
last line yet ?
no
A
yes
OUTPUT
processed summary
call TABLE91
STOP

Figure 7: Flow Diagram of Algorithm PAVE91.

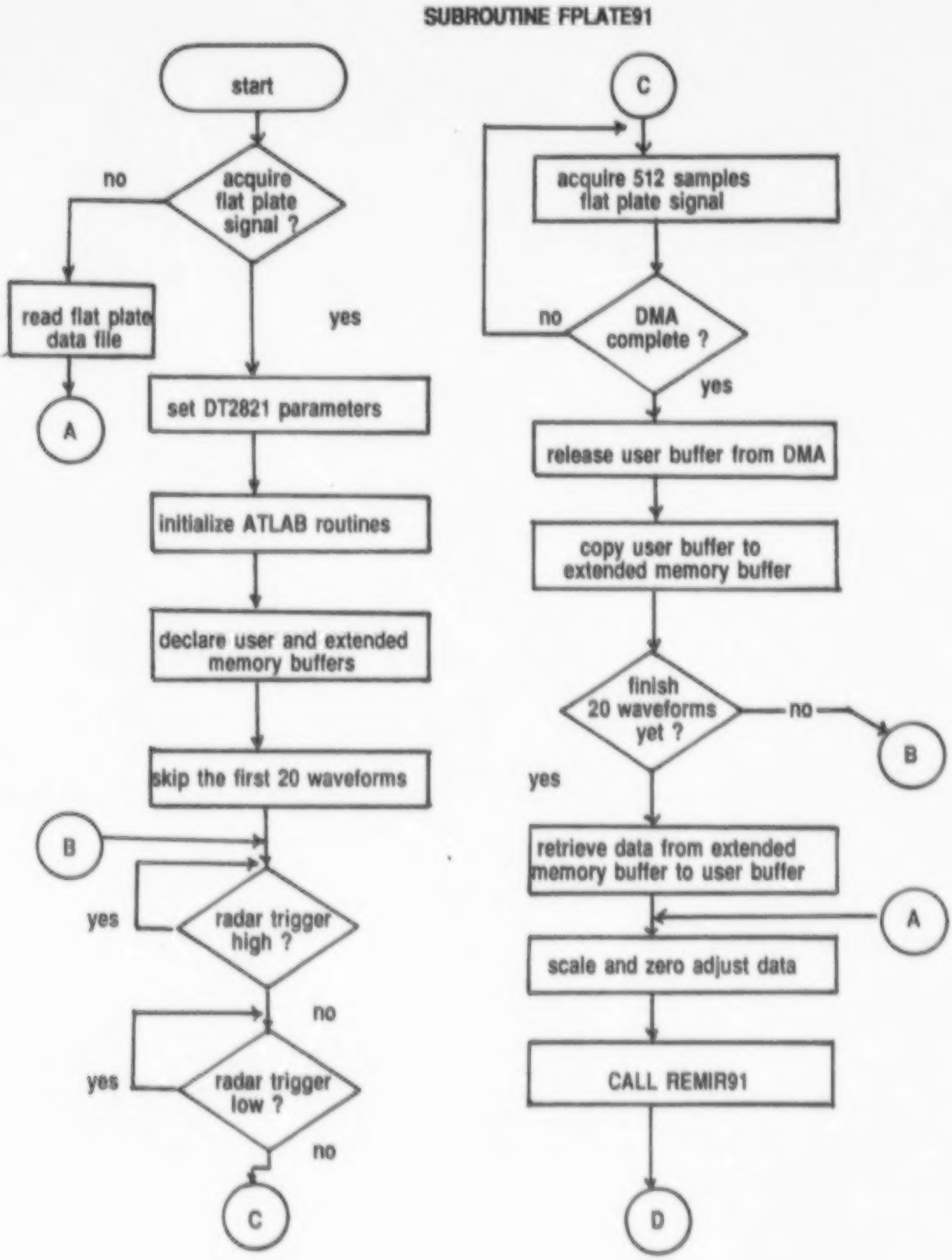

SUBROUTINE FPLATE91
start
acquire flat plate signal ?
no
read flat plate data file
A
yes
set DT2821 parameters
initialize ATLAB routines
declare user and extended memory buffers
skip the first 20 waveforms
B
yes
radar trigger high ?
no
yes
radar trigger low ?
no
C
C
acquire 512 samples flat plate signal
no
DMA complete ?
yes
release user buffer from DMA
copy user buffer to extended memory buffer
finish 20 waveforms yet ?
no
B
yes
retrieve data from extended memory buffer to user buffer
A
scale and zero adjust data
CALL REMIR91
D

Figure 8: Flow Diagram of Algorithm FPLATE91.

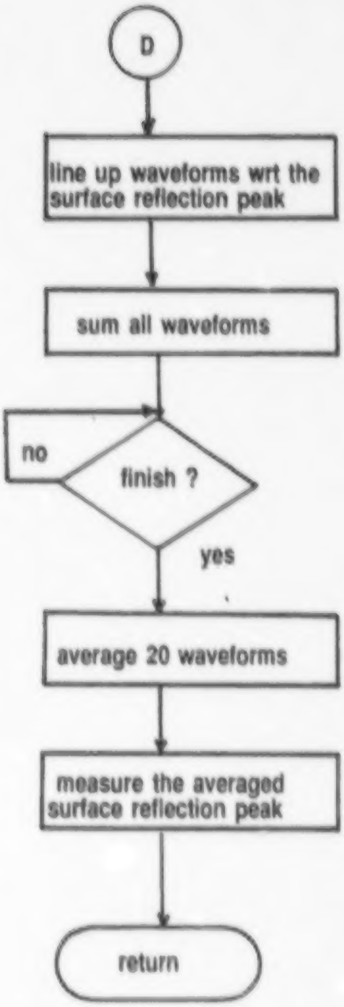

D
line up waveforms wrt the surface reflection peak
sum all waveforms
no
finish ?
yes
average 20 waveforms
measure the averaged surface reflection peak
return

Figure 8 (continued): Flow Diagram of Algorithm FPLATE91.

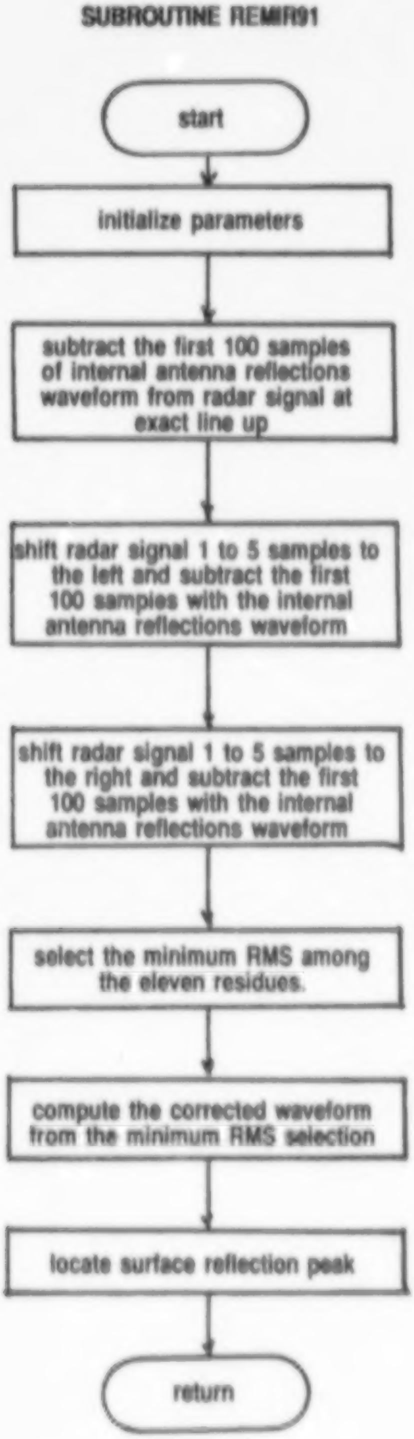

SUBROUTINE REMIR91
start
initialize parameters
subtract the first 100 samples of internal antenna reflections waveform from radar signal at exact line up
shift radar signal 1 to 5 samples to the left and subtract the first 100 samples with the internal antenna reflections waveform
shift radar signal 1 to 5 samples to the right and subtract the first 100 samples with the internal antenna reflections waveform
select the minimum RMS among the eleven residues.
compute the corrected waveform from the minimum RMS selection
locate surface reflection peak
return

Figure 9: Flow Diagram of Algorithm REMIR91.

SUBROUTINE SIGPRO91

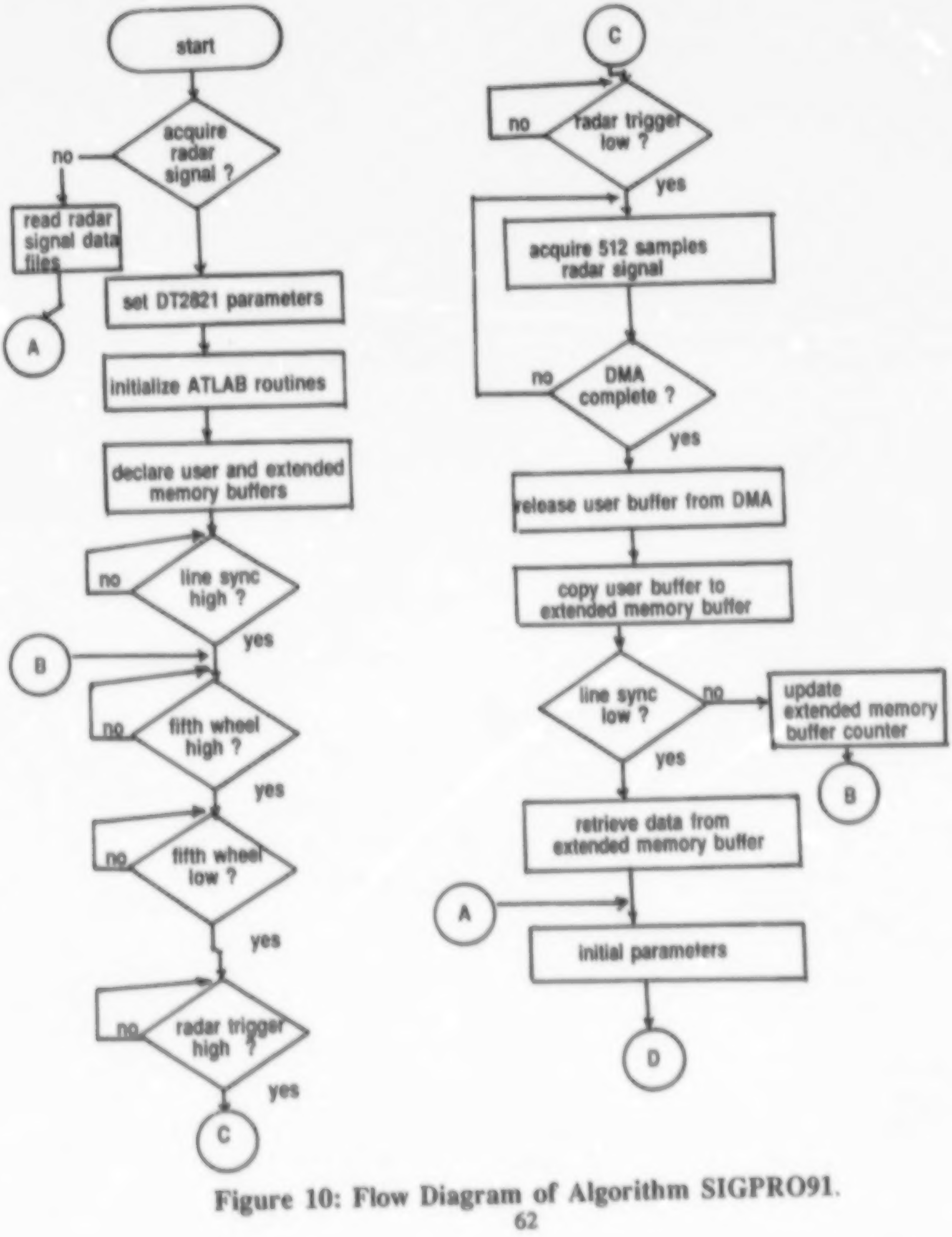

start
acquire radar signal ?
no
read radar signal data files
A
set DT2821 parameters
initialize ATLAB routines
declare user and extended memory buffers
no
line sync high ?
yes
B
no
fifth wheel high ?
yes
no
fifth wheel low ?
yes
no
radar trigger high ?
yes
C
C
no
radar trigger low ?
yes
acquire 512 samples radar signal
no
DMA complete ?
yes
release user buffer from DMA
copy user buffer to extended memory buffer
line sync low ?
no
update extended memory buffer counter
B
yes
retrieve data from extended memory buffer
A
initial parameters
D

Figure 10: Flow Diagram of Algorithm SIGPRO91.

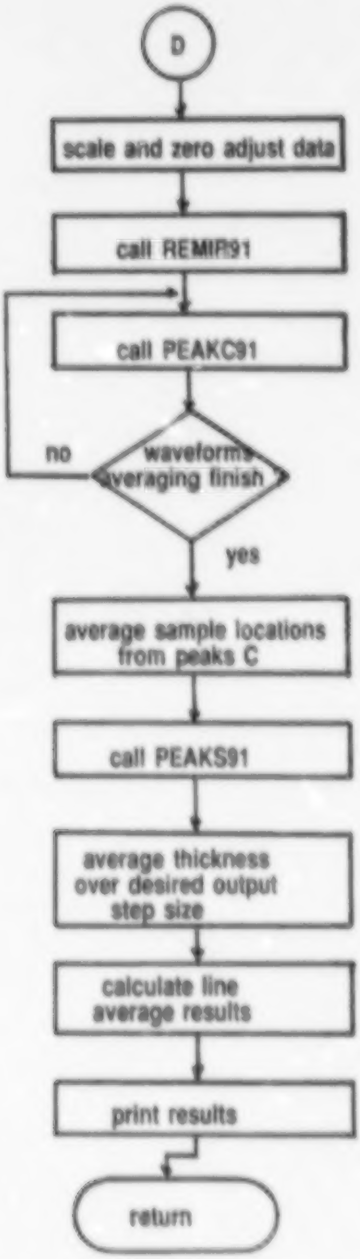

D
scale and zero adjust data
call REMIR91
call PEAKC91
no
waveforms averaging finish
yes
average sample locations from peaks C
call PEAKS91
average thickness over desired output step size
calculate line average results
print results
return

Figure 10 (continued): Flow Diagram of Algorithm SIGPRO91.

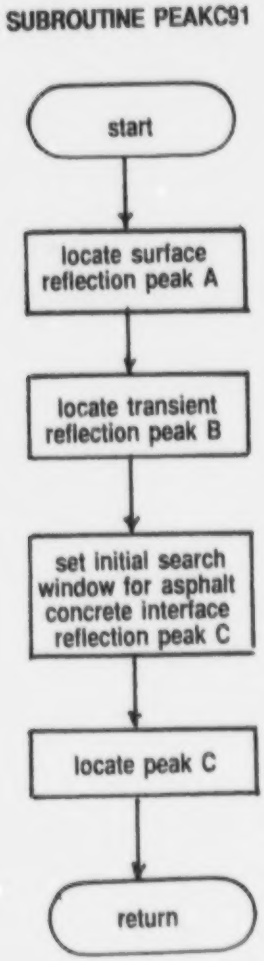

SUBROUTINE PEAKC91
start
locate surface reflection peak A
locate transient reflection peak B
set initial search window for asphalt concrete interface reflection peak C
locate peak C
return

Figure 11: Flow Diagram of Algoritm PEAKC91.

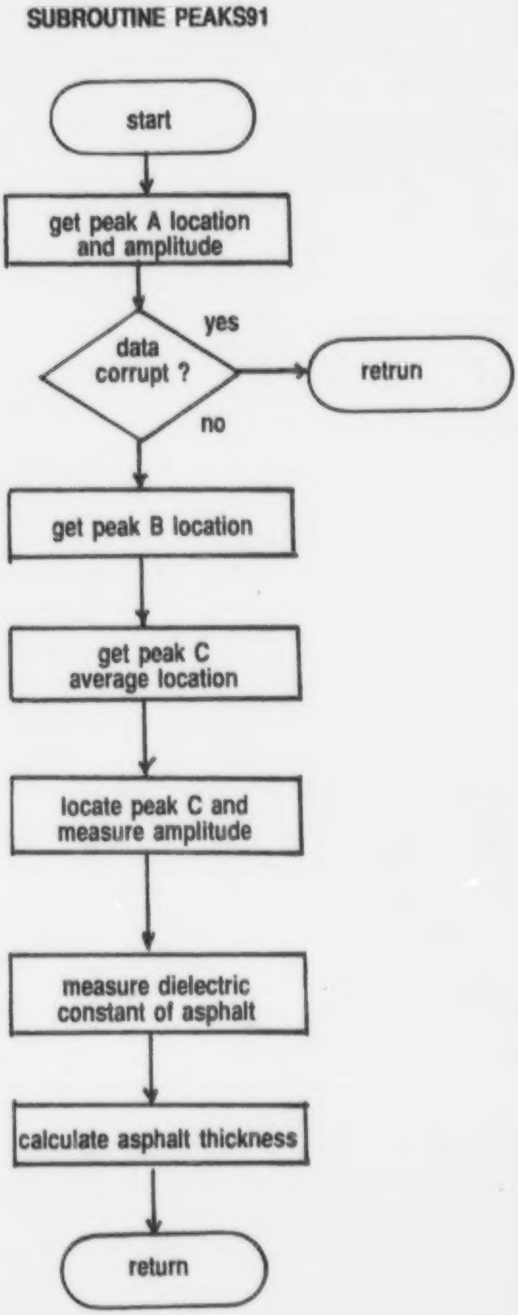

SUBROUTINE PEAKS91
start
get peak A location and amplitude
data corrupt ?
yes
retrun
no
get peak B location
get peak C average location
locate peak C and measure amplitude
measure dielectric constant of asphalt
calculate asphalt thickness
return

Figure 12: Flow Diagram of Algorithm PEAKS91.

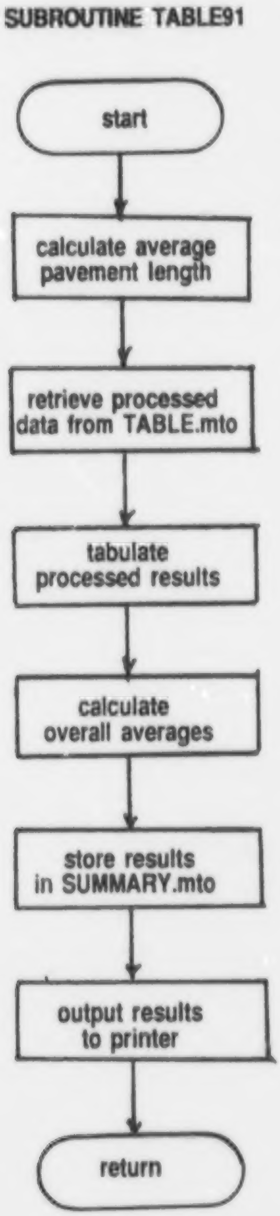

SUBROUTINE TABLE91
start
calculate average pavement length
retrieve processed data from TABLE.mto
tabulate processed results
calculate overall averages
store results in SUMMARY.mto
output results to printer
return

Figure 13: Flow Diagram of Algorithm TABLE91.

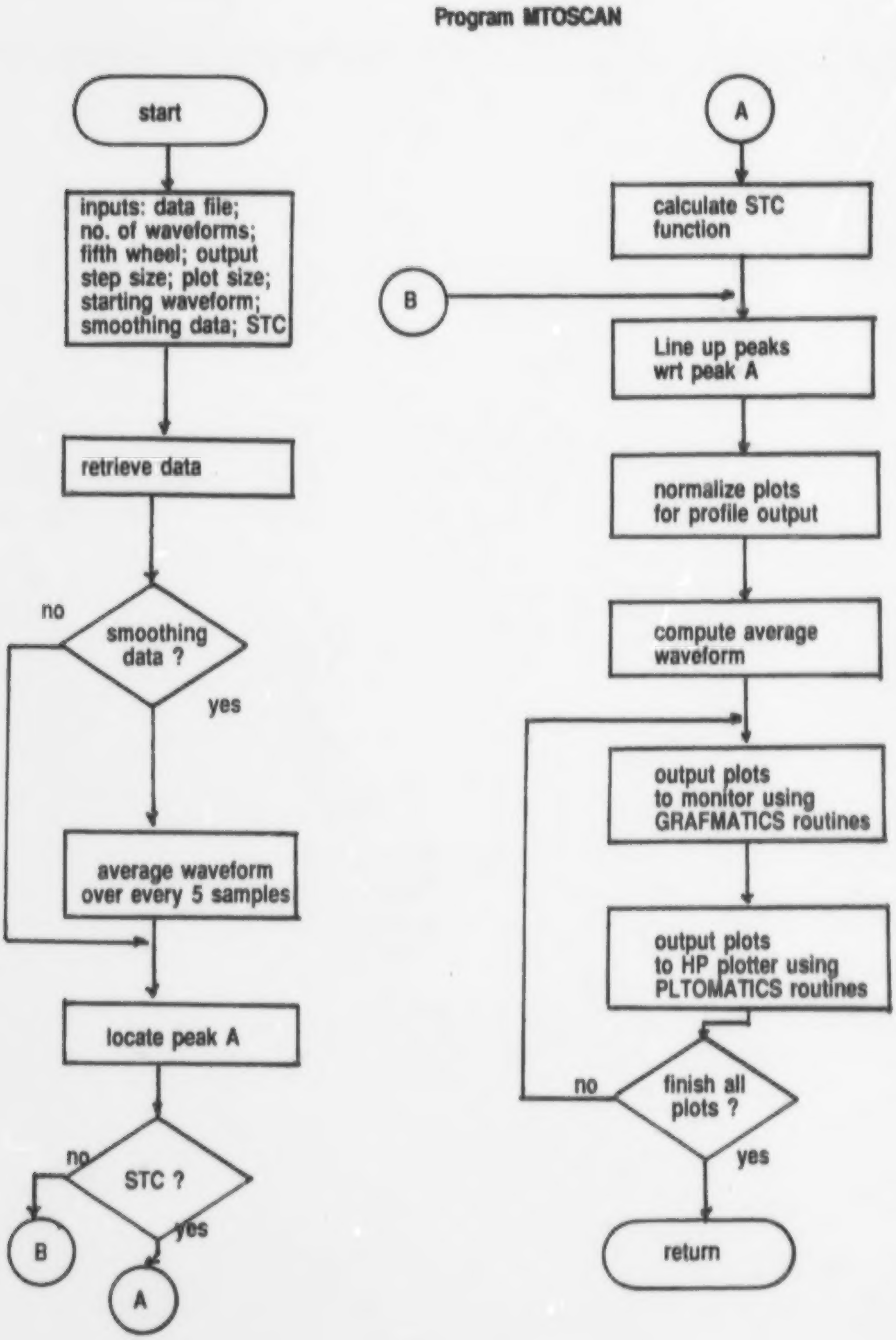

Program MTOSCAN
start
inputs: data file; no. of waveforms; fifth wheel; output step size; plot size; starting waveform; smoothing data; STC
retrieve data
smoothing data ?
no
yes
average waveform over every 5 samples
locate peak A
STC ?
no
yes
B
A
A
calculate STC function
B
Line up peaks wrt peak A
normalize plots for profile output
compute average waveform
output plots to monitor using GRAFMATICS routines
output plots to HP plotter using PLTOMATICS routines
finish all plots ?
no
yes
return

Figure 14: Flow Diagram of Algorithm MTOSCAN.

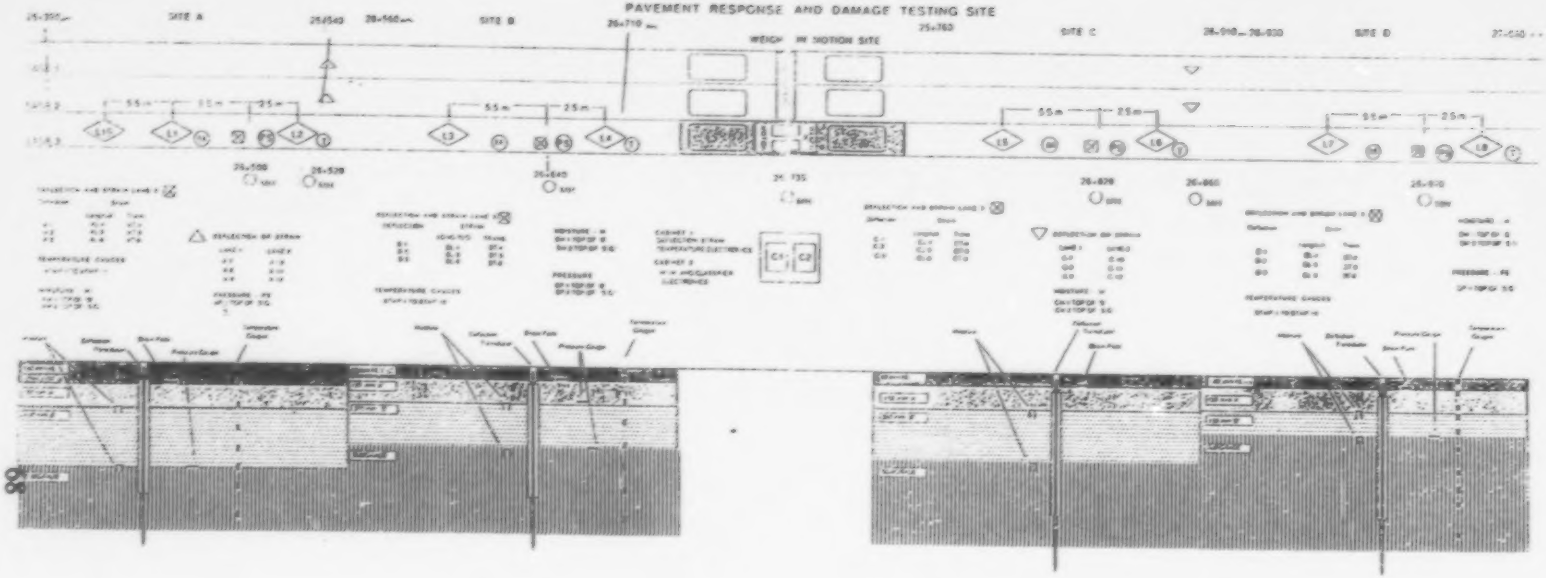

PAVEMENT RESPONSE AND DAMAGE TESTING SITE
SITE A
SITE B
SITE C
SITE D
WEIGH IN MOTION SITE
25+540
26+710
25+760
25+500
26+520
26+640
26+820
26+860
5.5 m
2.5 m
L1
L2
L3
L4
L5
L6
L7
L8
C1
C2

Fig 15: Cross-section of pavement structure at Hwy. 7/Dufferin in Thornhill.

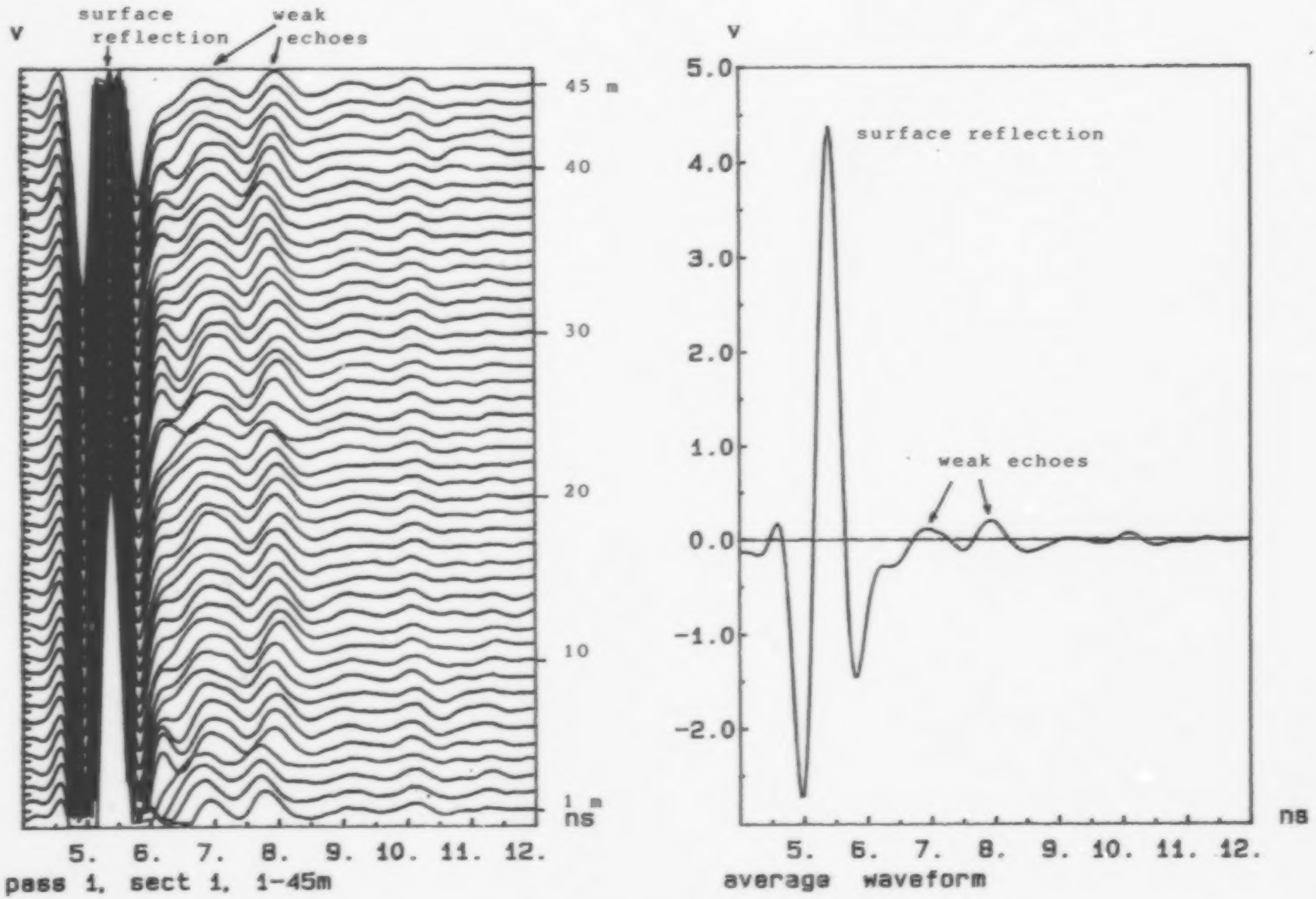


Fig 16: Hwy. 7/Dufferin (1989) - Waveforms from Line 1 (1 - 45 m).

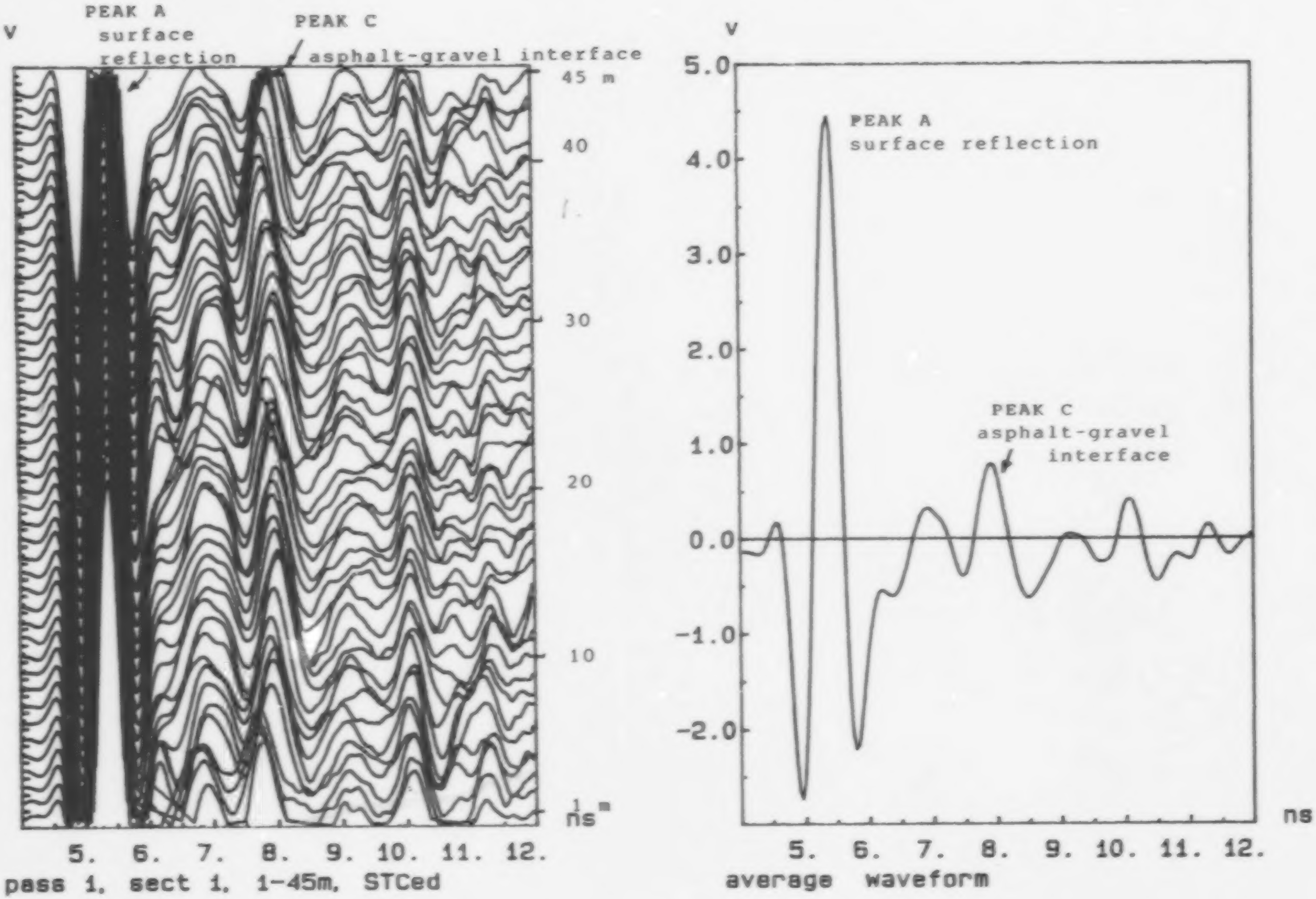


Fig 17: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (1 - 45 m).

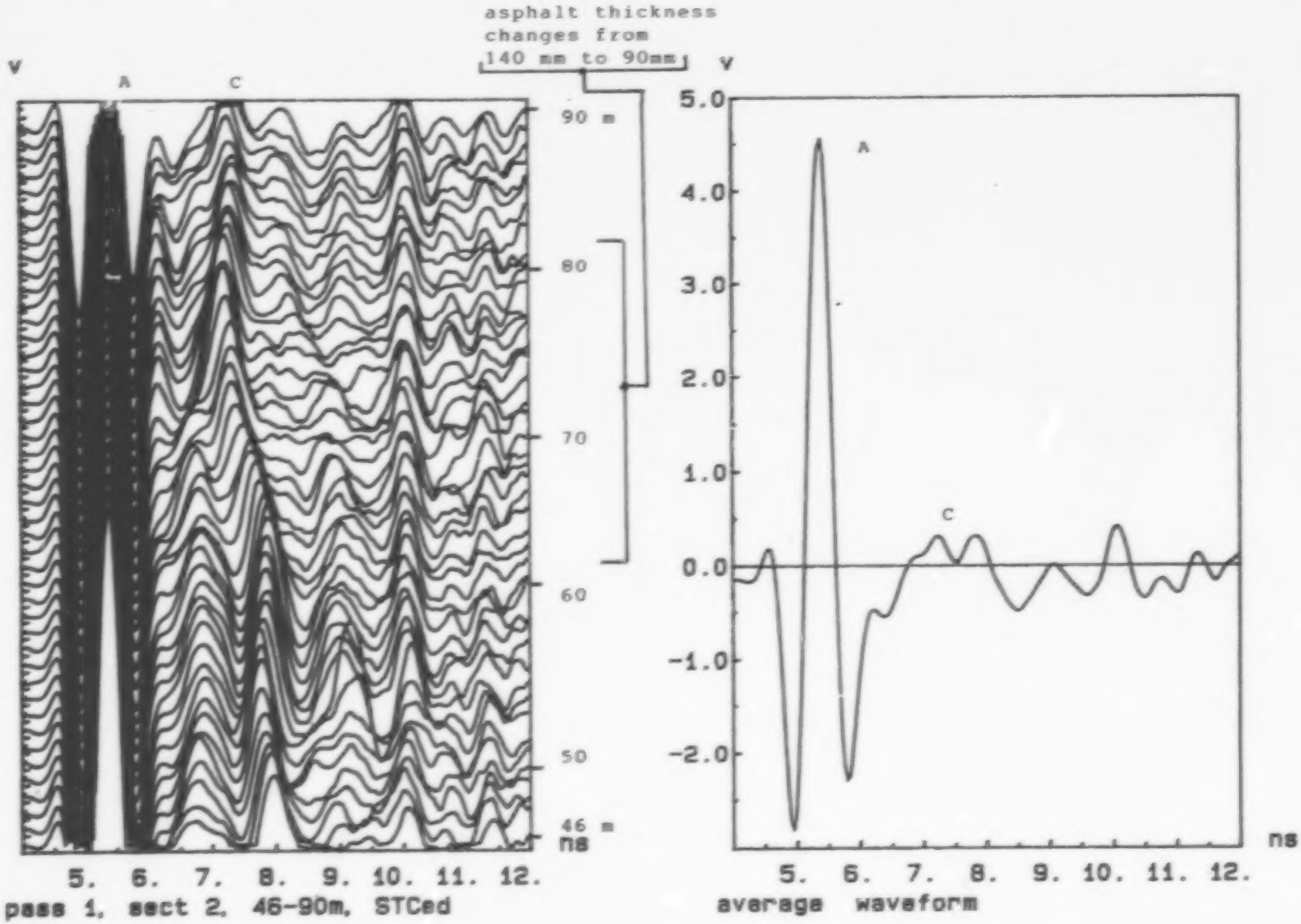


Fig 18: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (46 - 90 m).

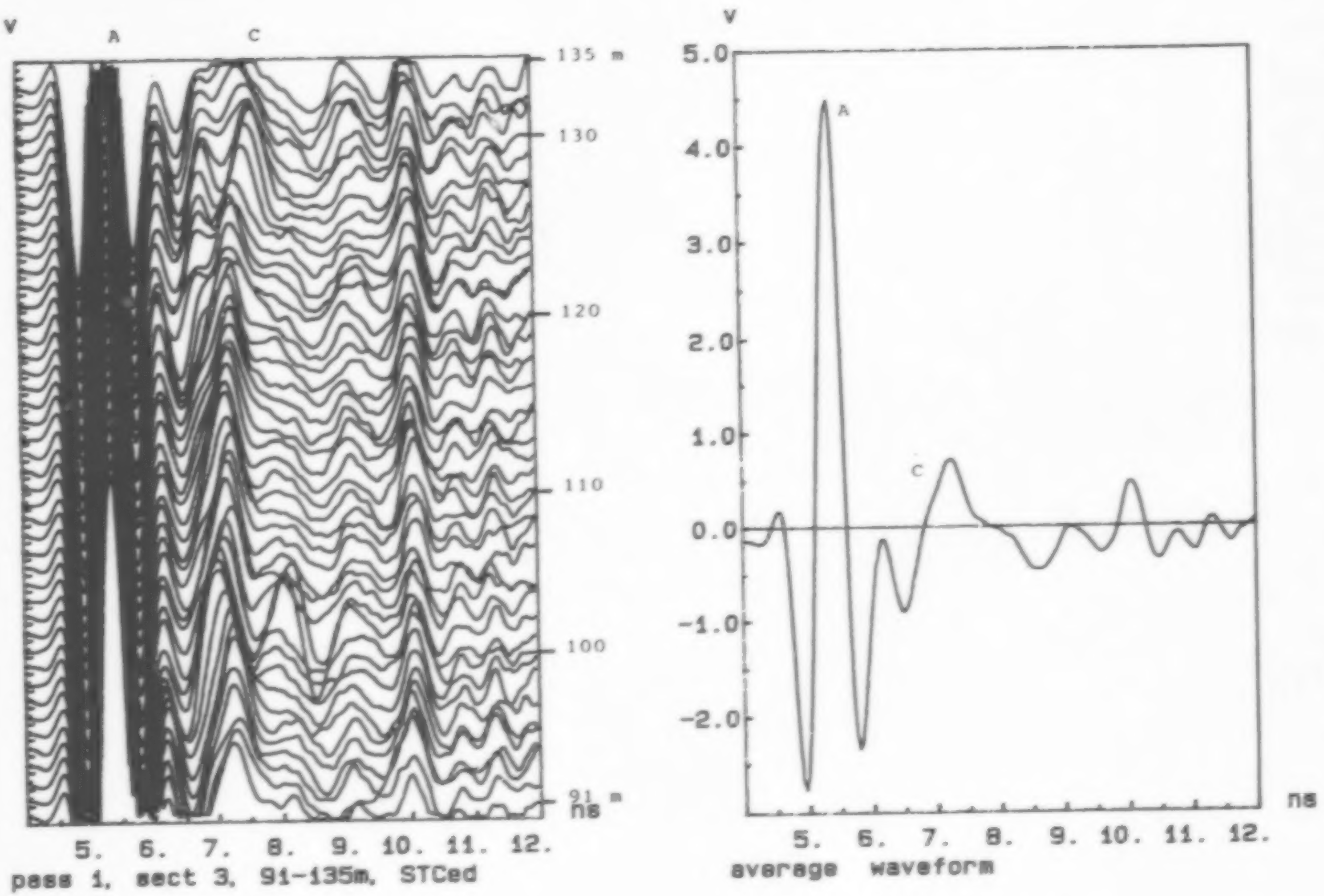


Fig 19: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (91 - 135 m).

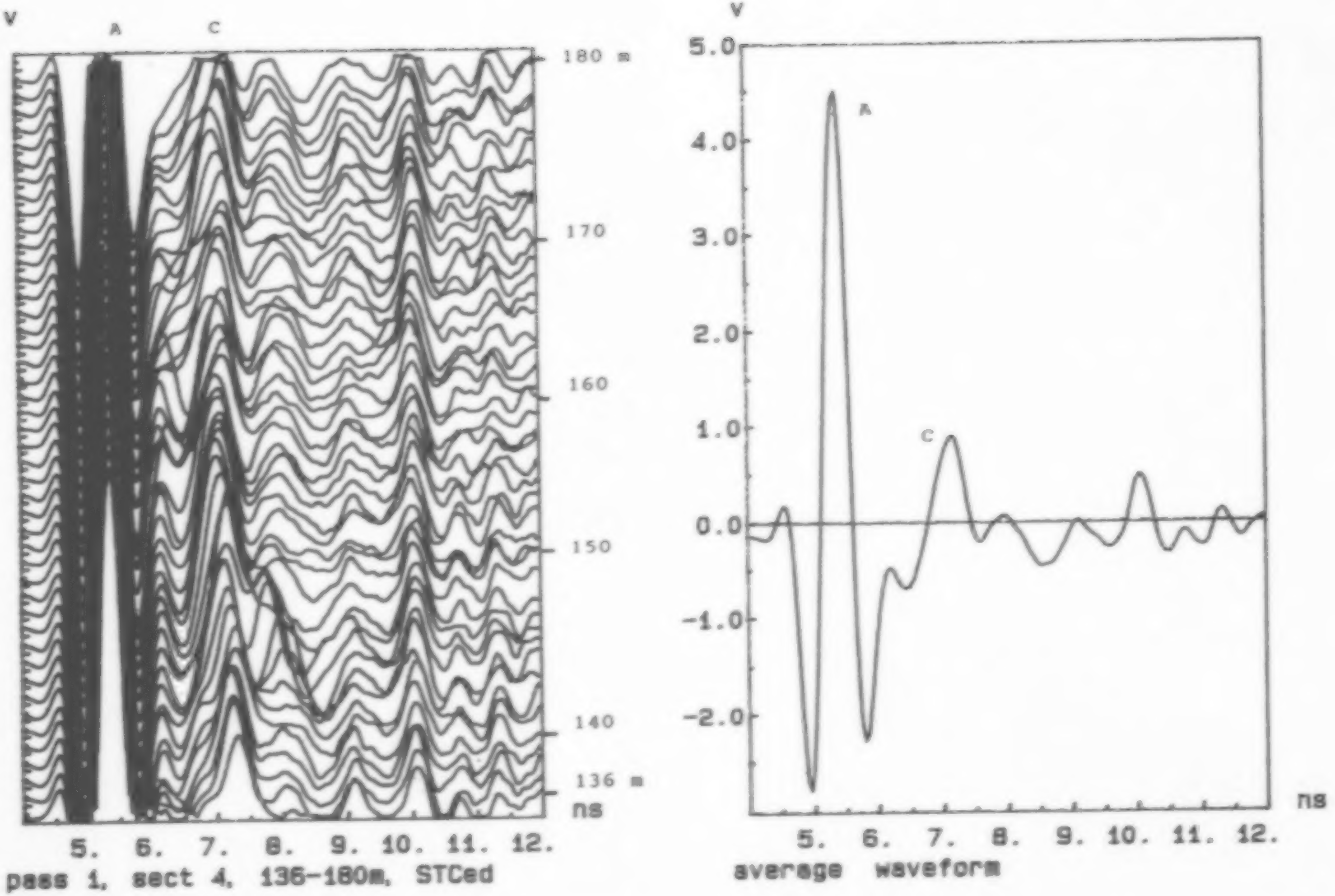


Fig 20: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (136 - 180 m).

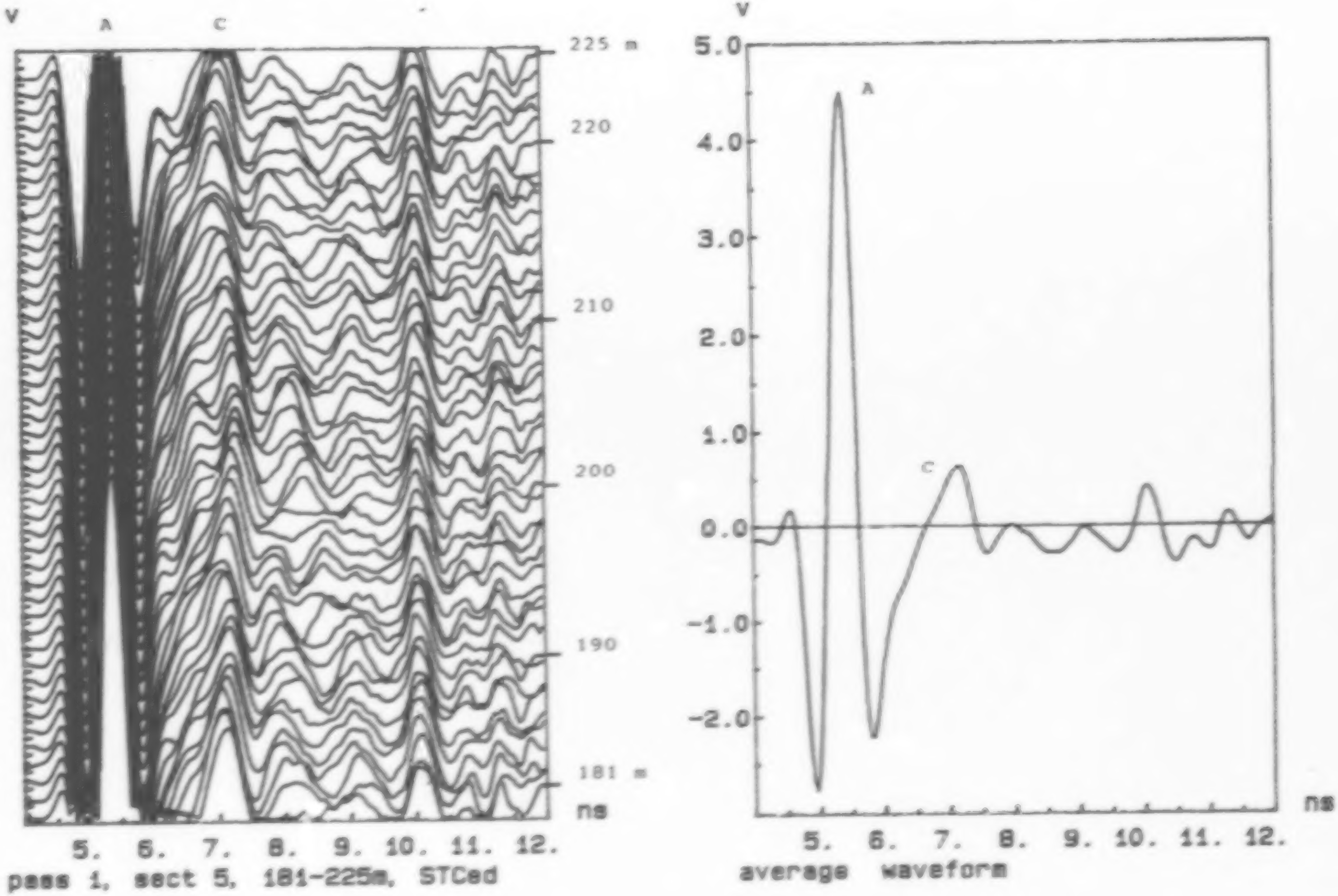


Fig 21: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (181 - 225 m).

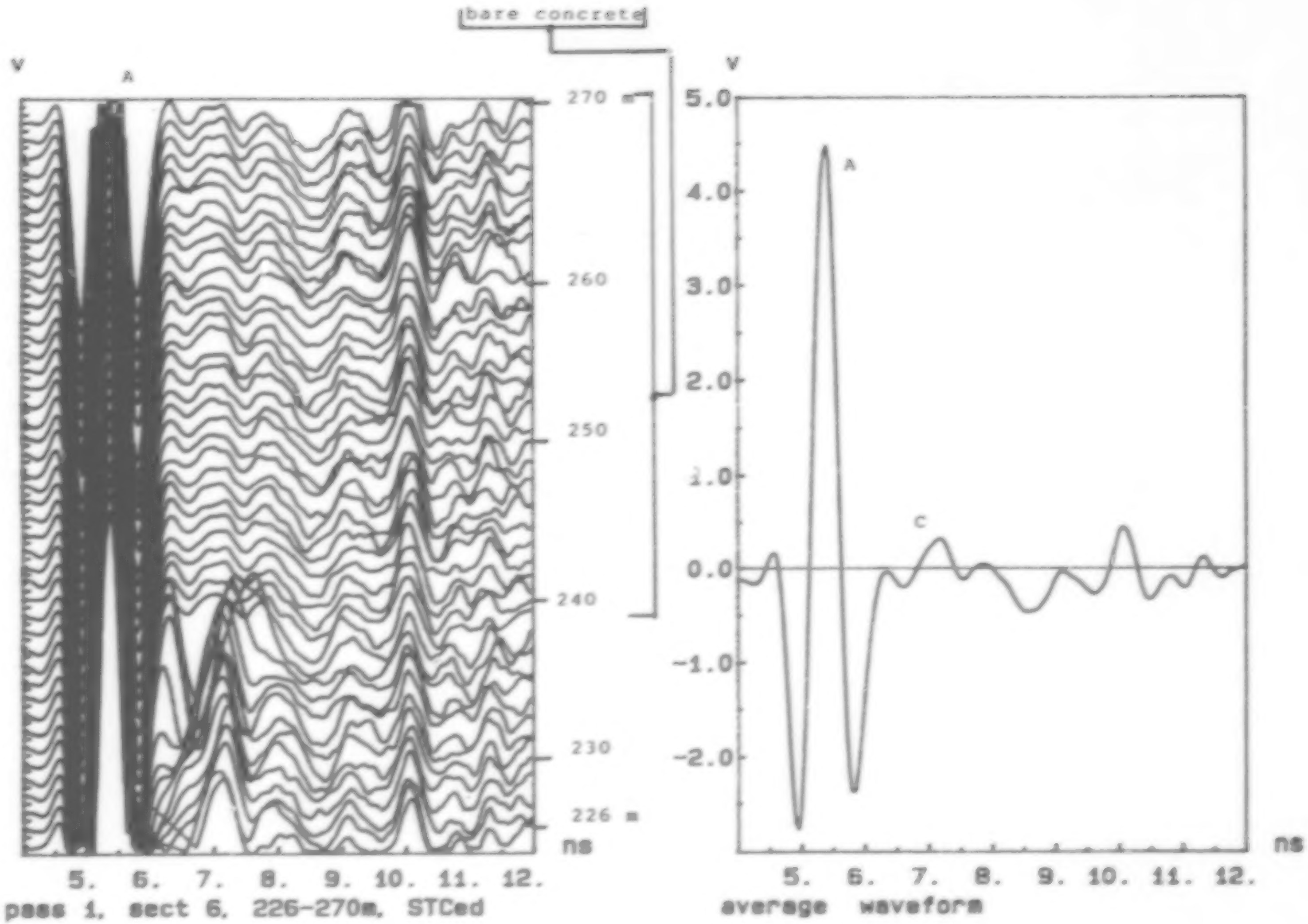


Fig 22: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (226 - 270 m).

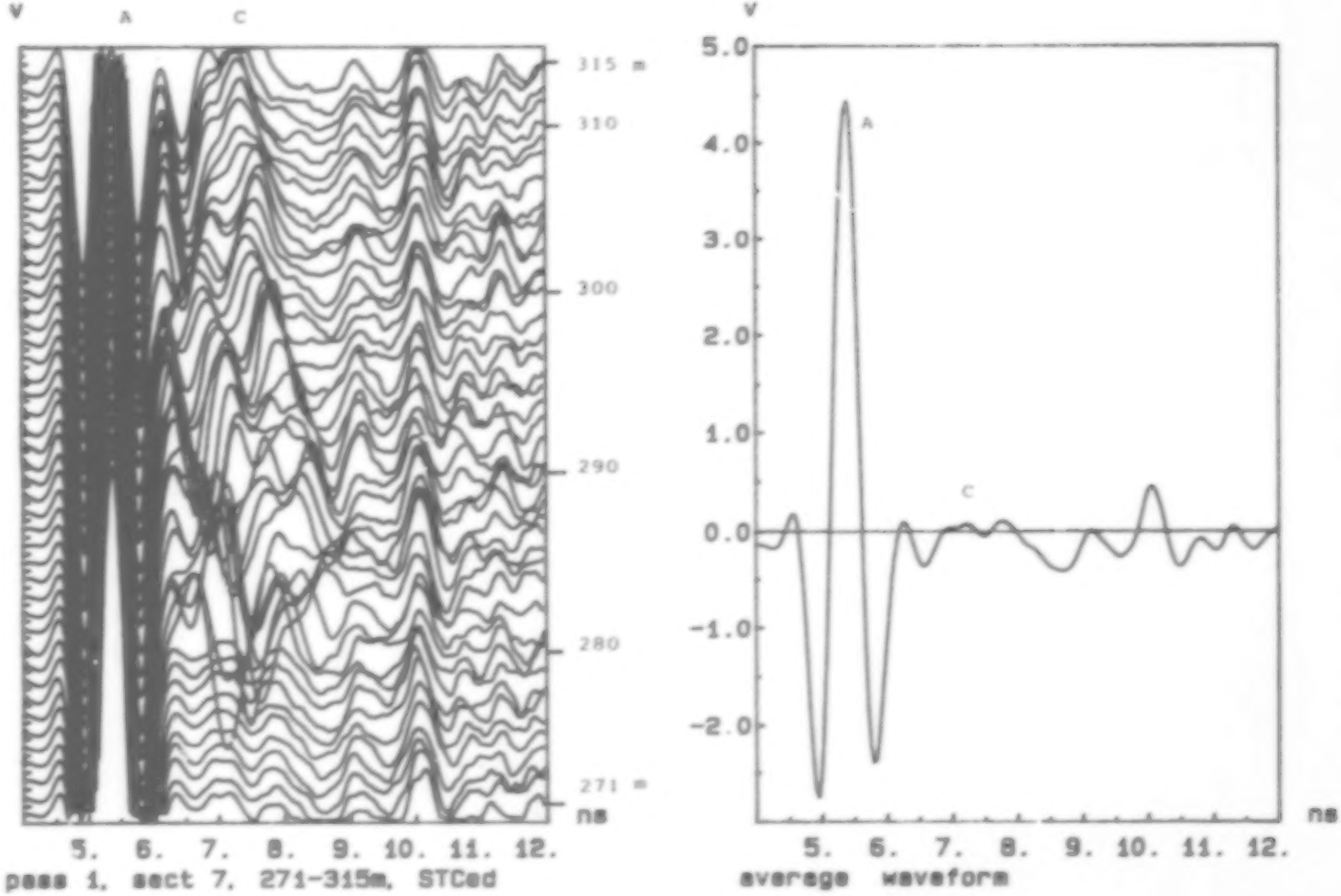


Fig 23: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (271 - 315 m).

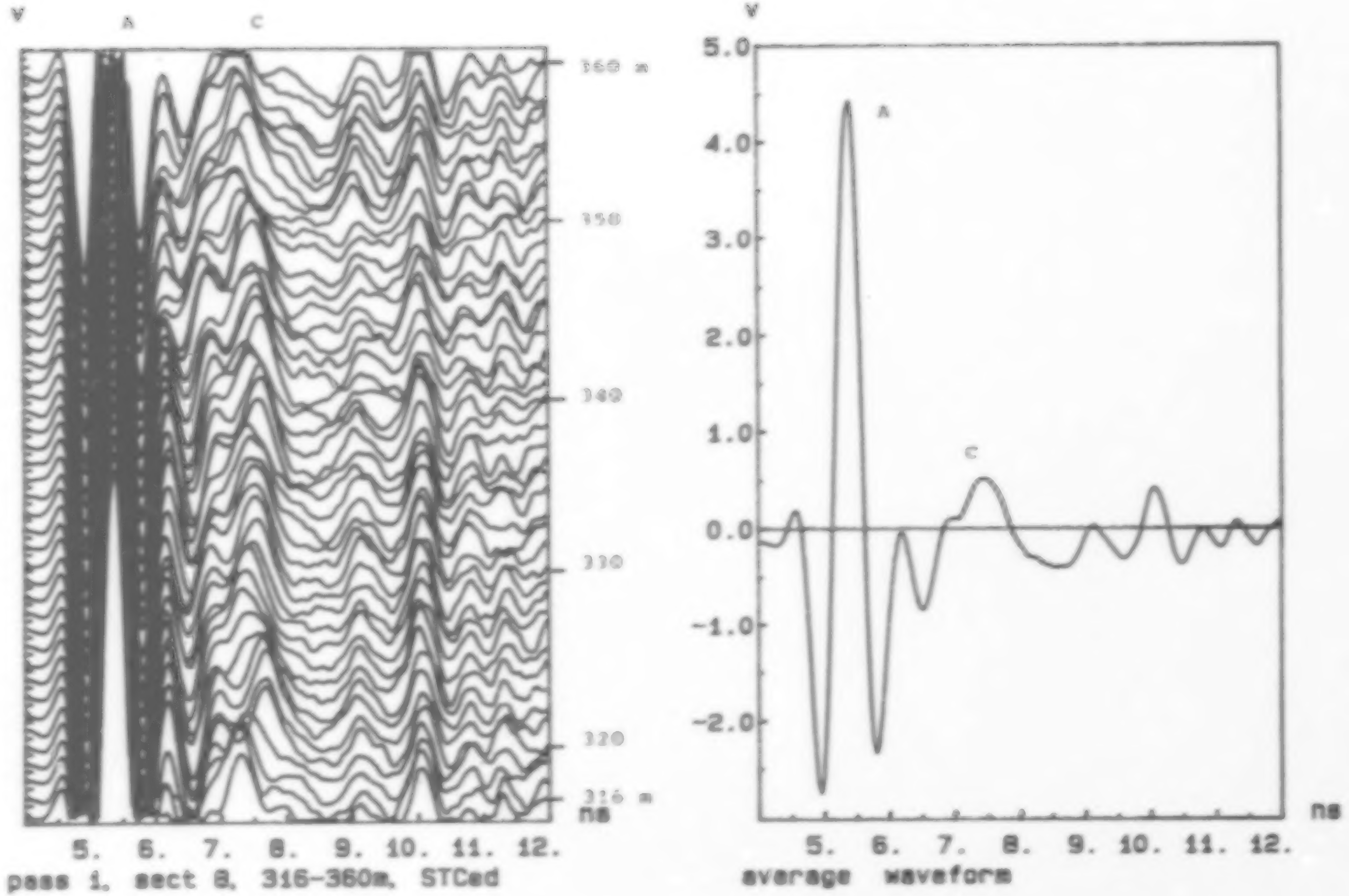


Fig 24: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (316 - 360 m).

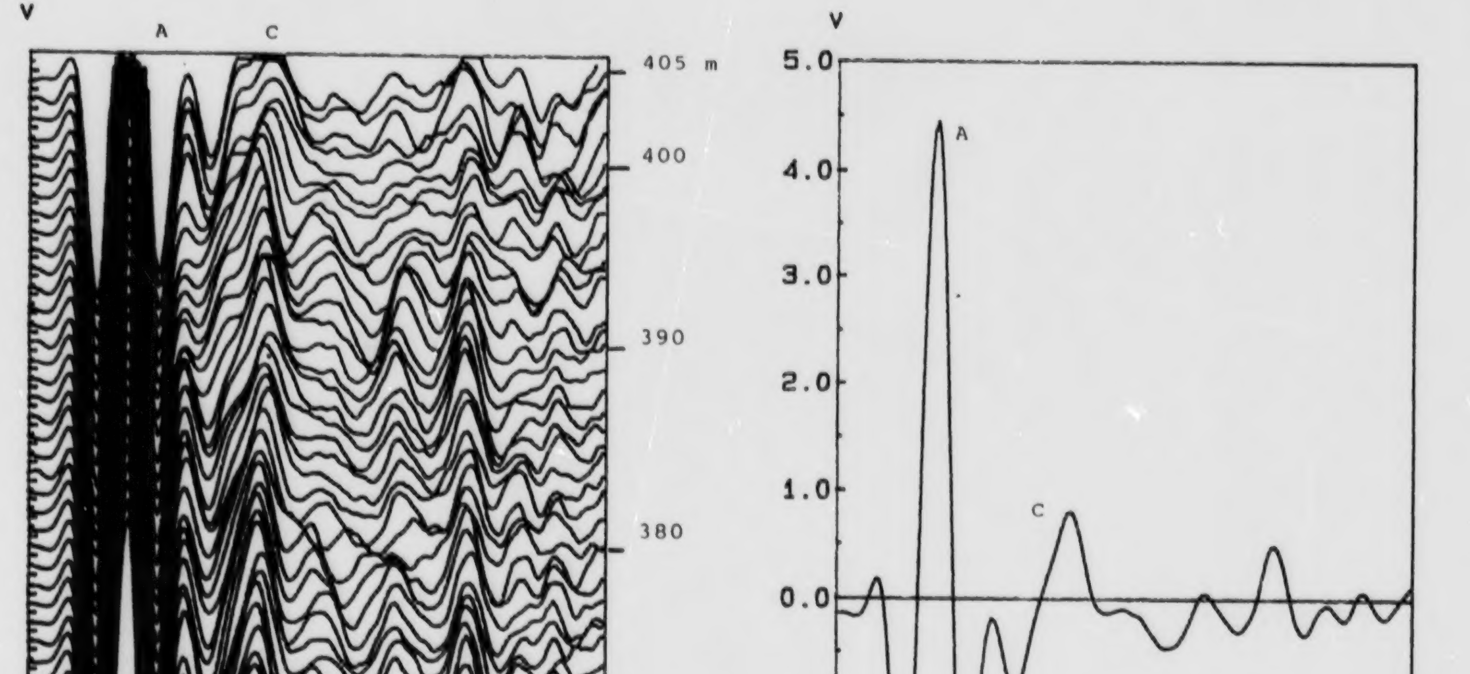


Fig 25: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (361 - 405 m).

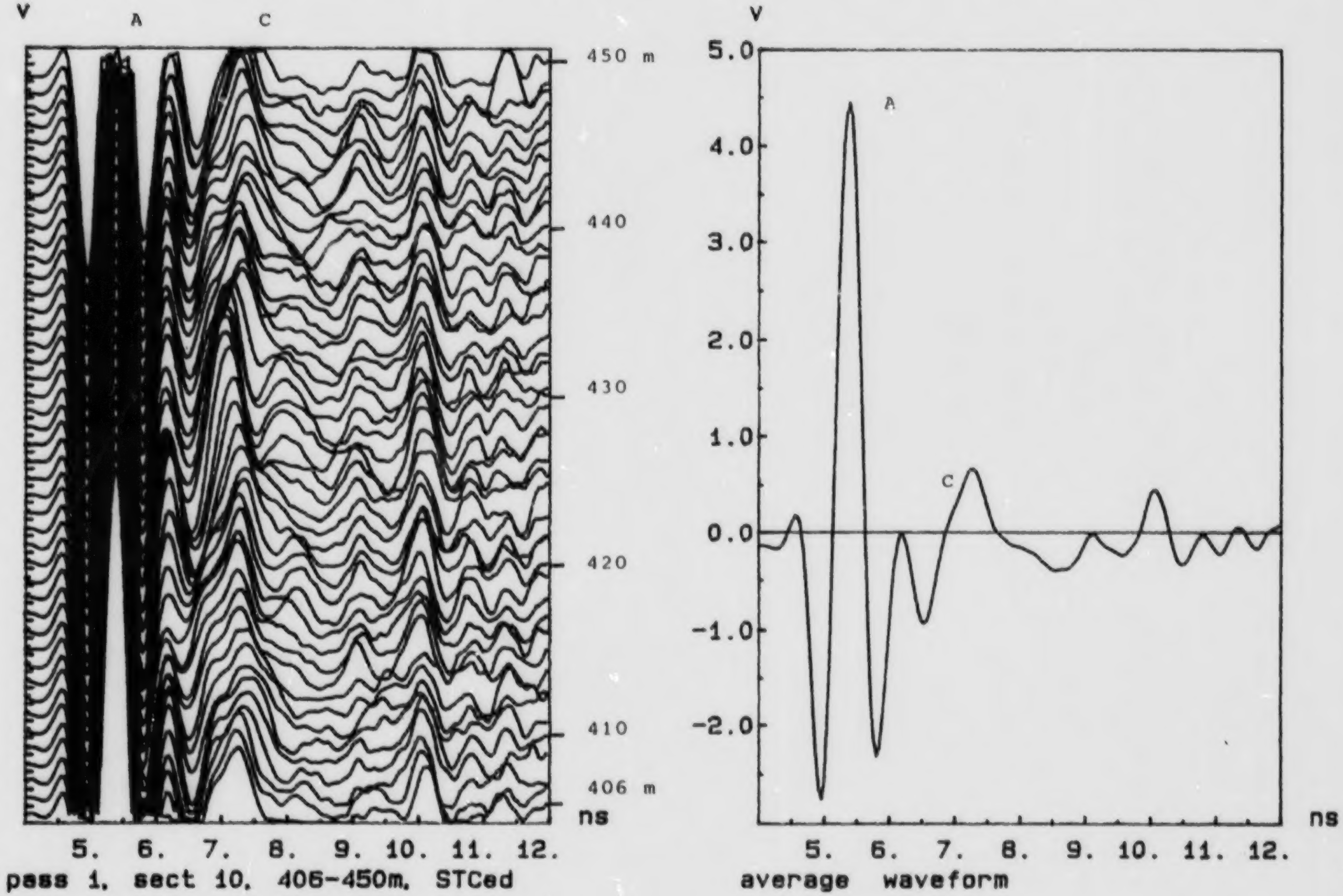


Fig 26: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (406 - 450 m).

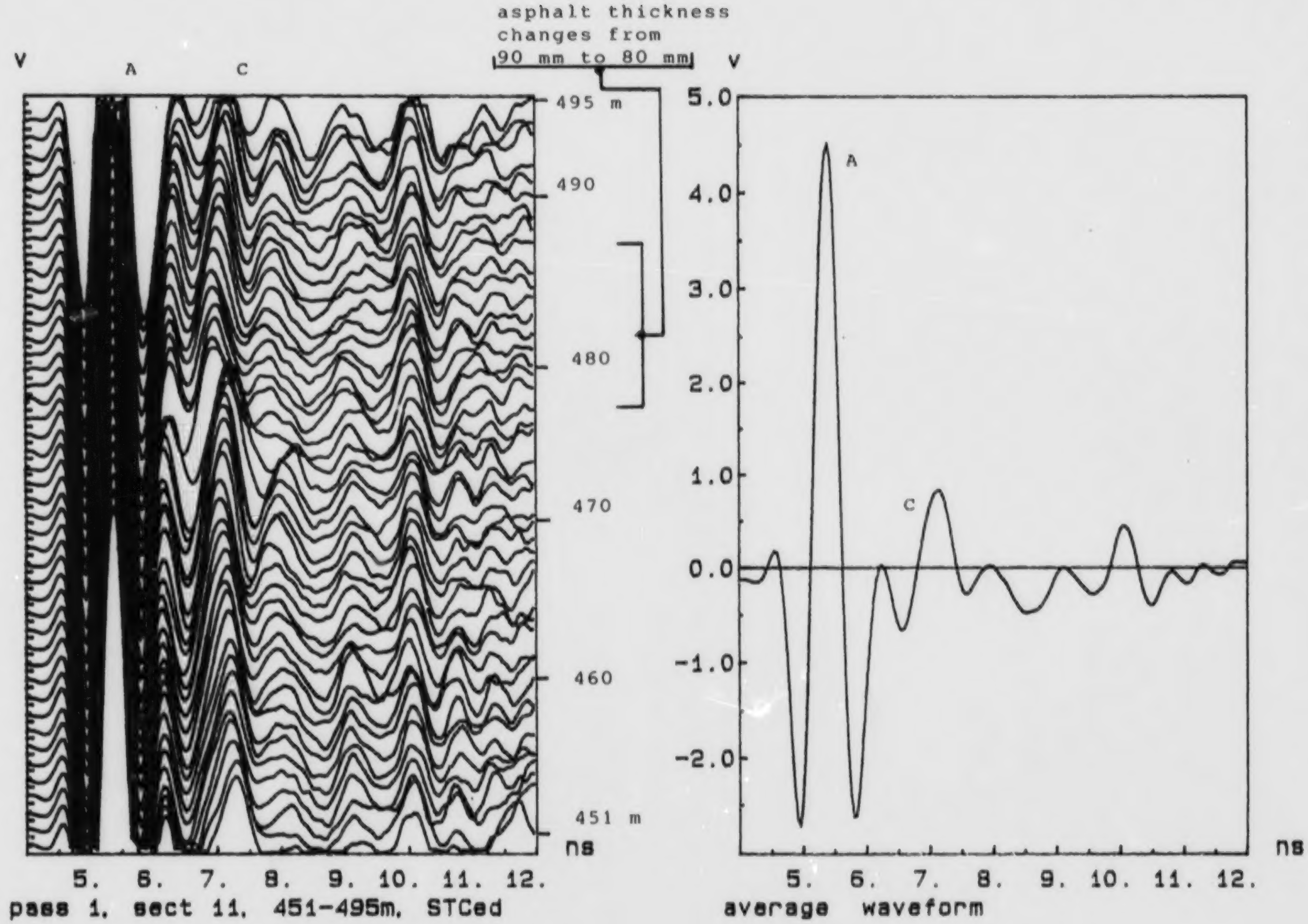


Fig 27: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (451 - 495 m).

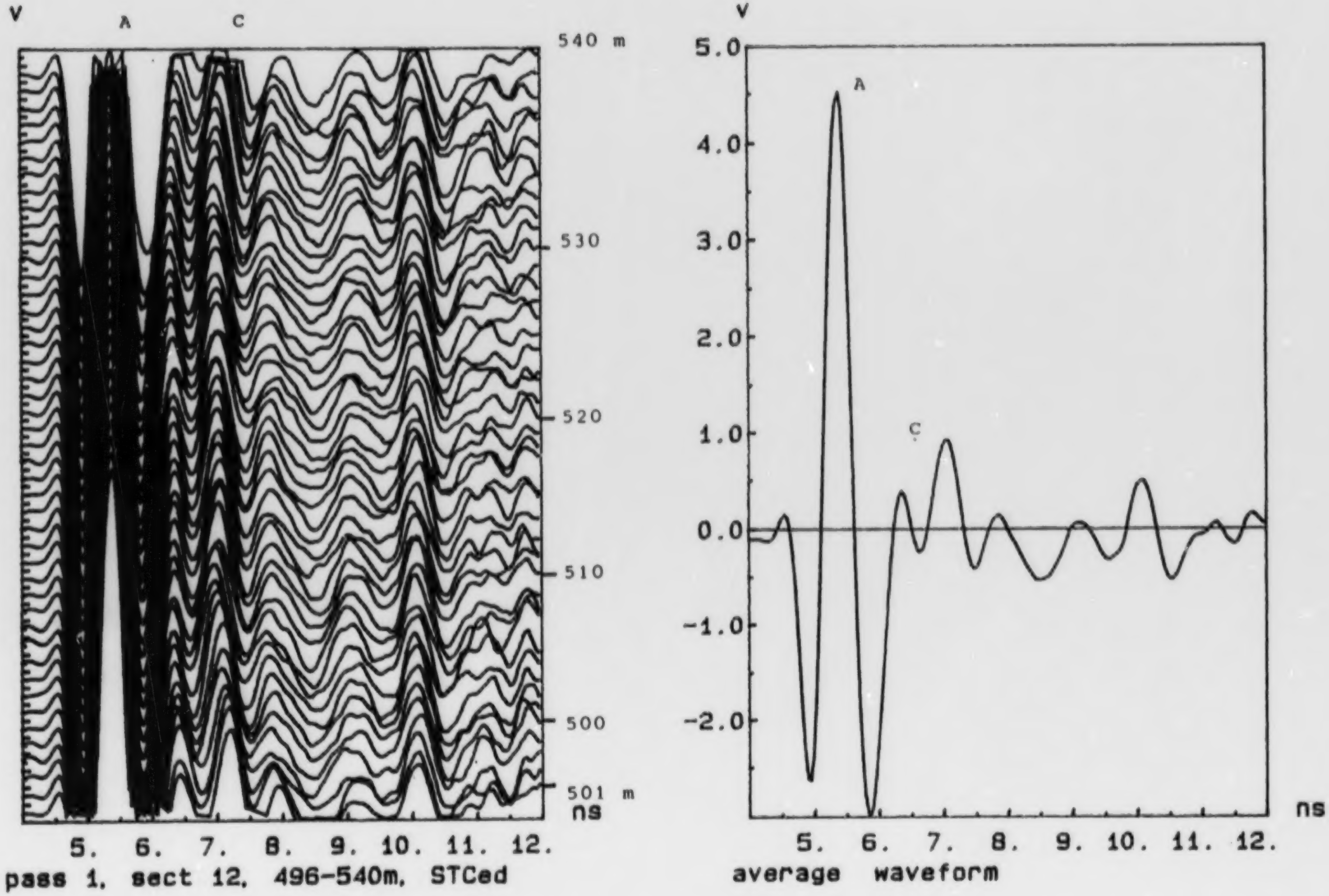


Fig 28: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (495 - 540 m).

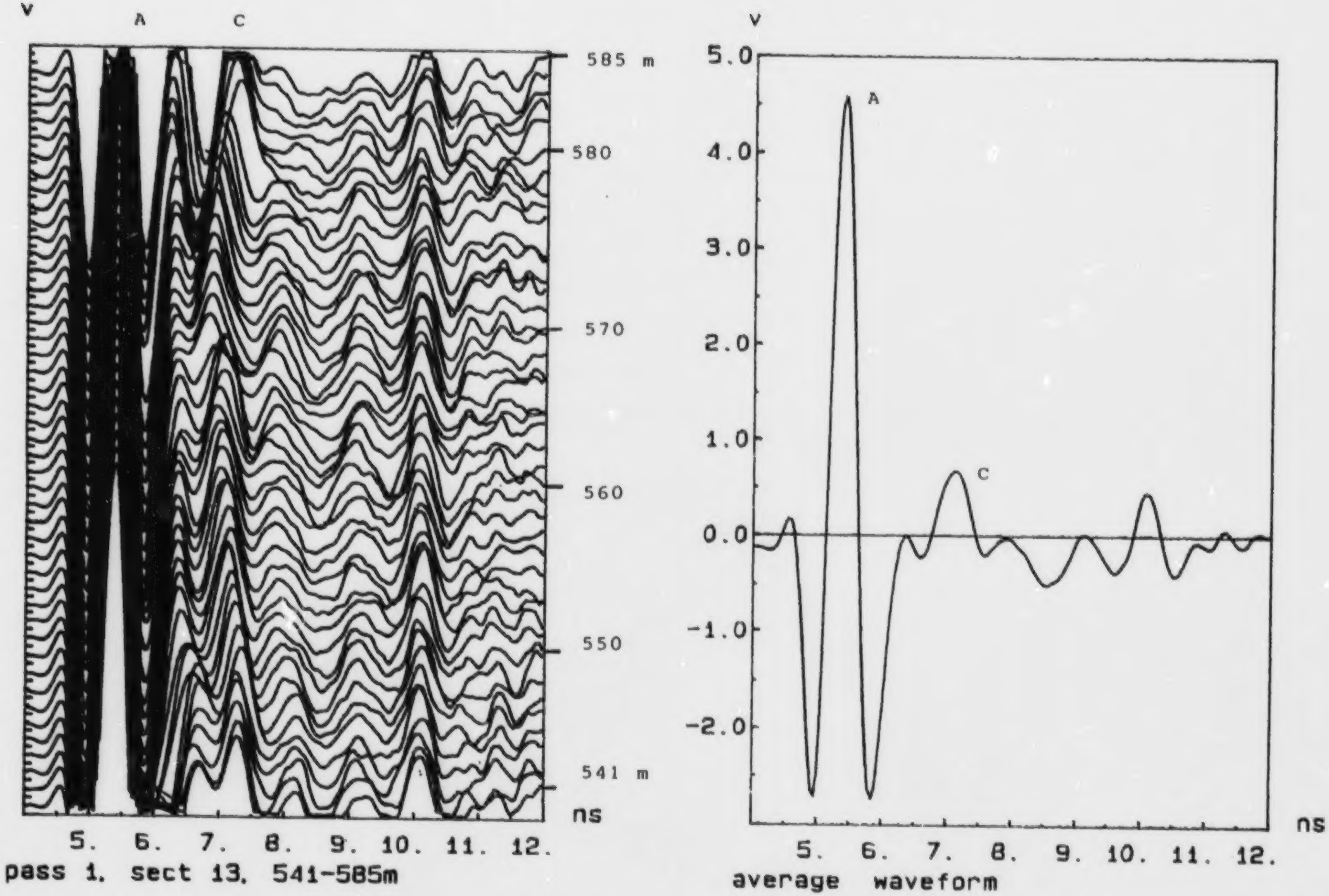


Fig 29: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (541 - 585 m).

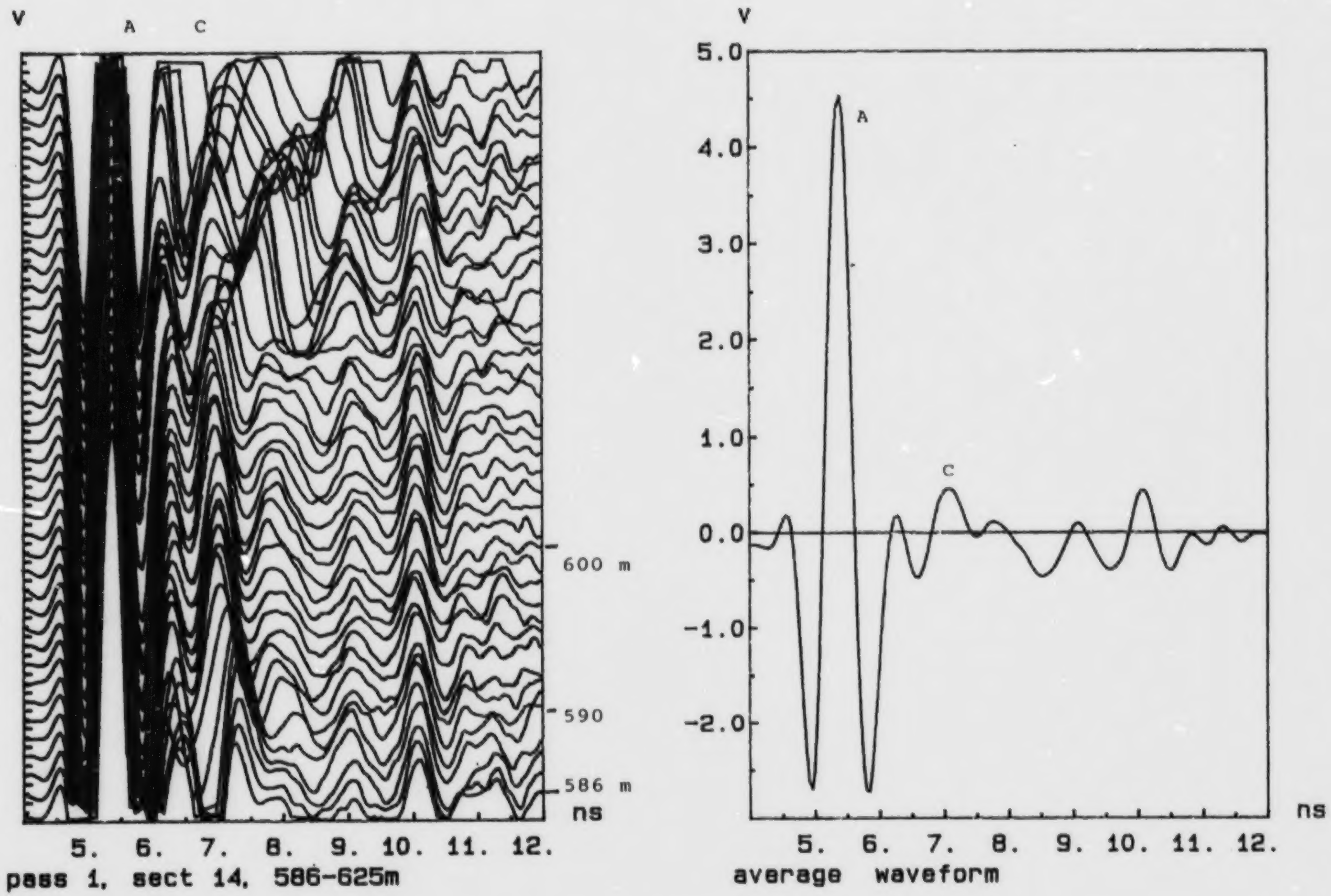


Fig 30: Hwy. 7/Dufferin (1989) - STC waveforms from Line 1 (586 - 625 m).

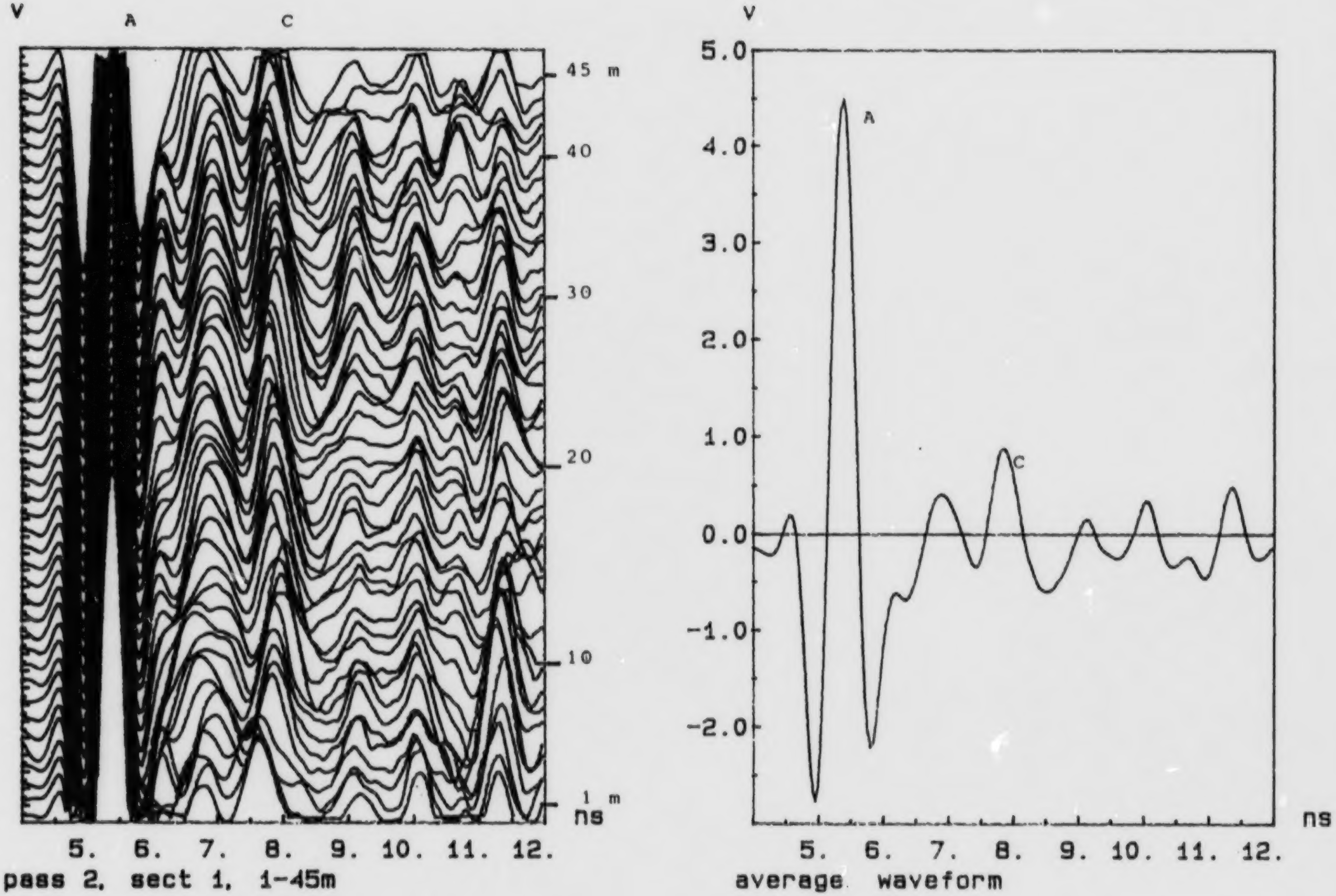


Fig 31: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (1 - 45 m).

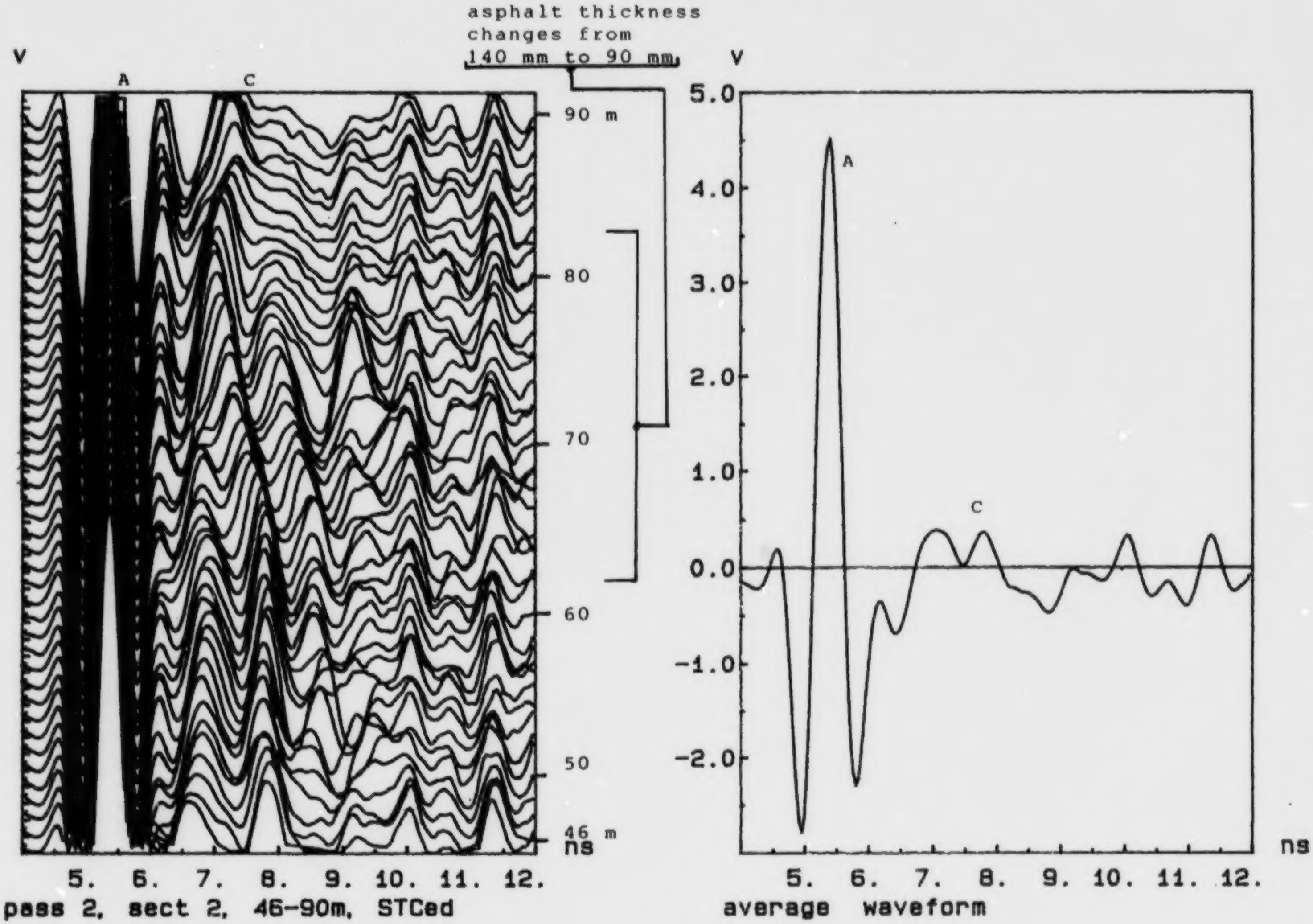


Fig 32: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (46 - 90 m).

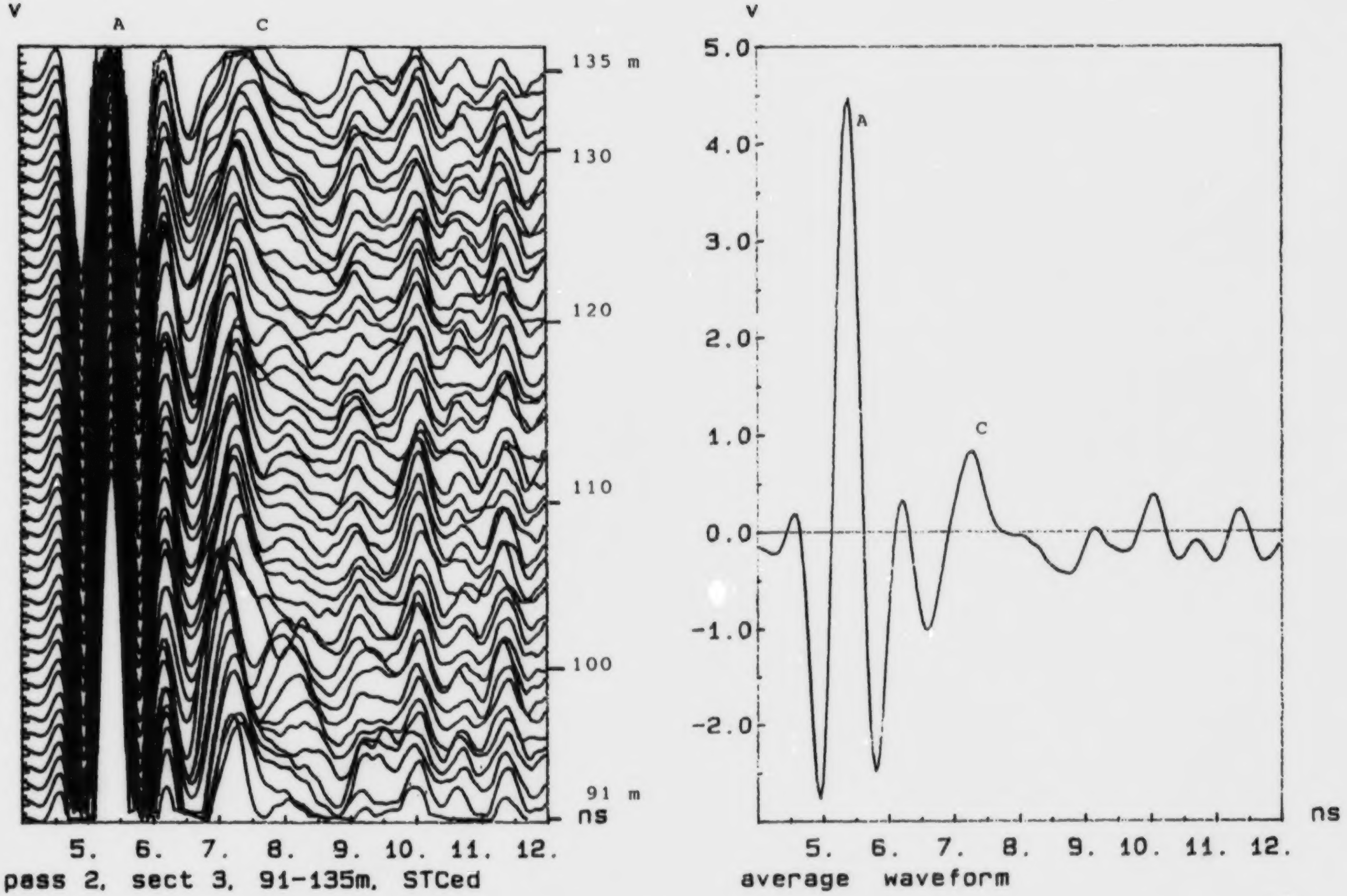


Fig 33: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (91 - 135 m).

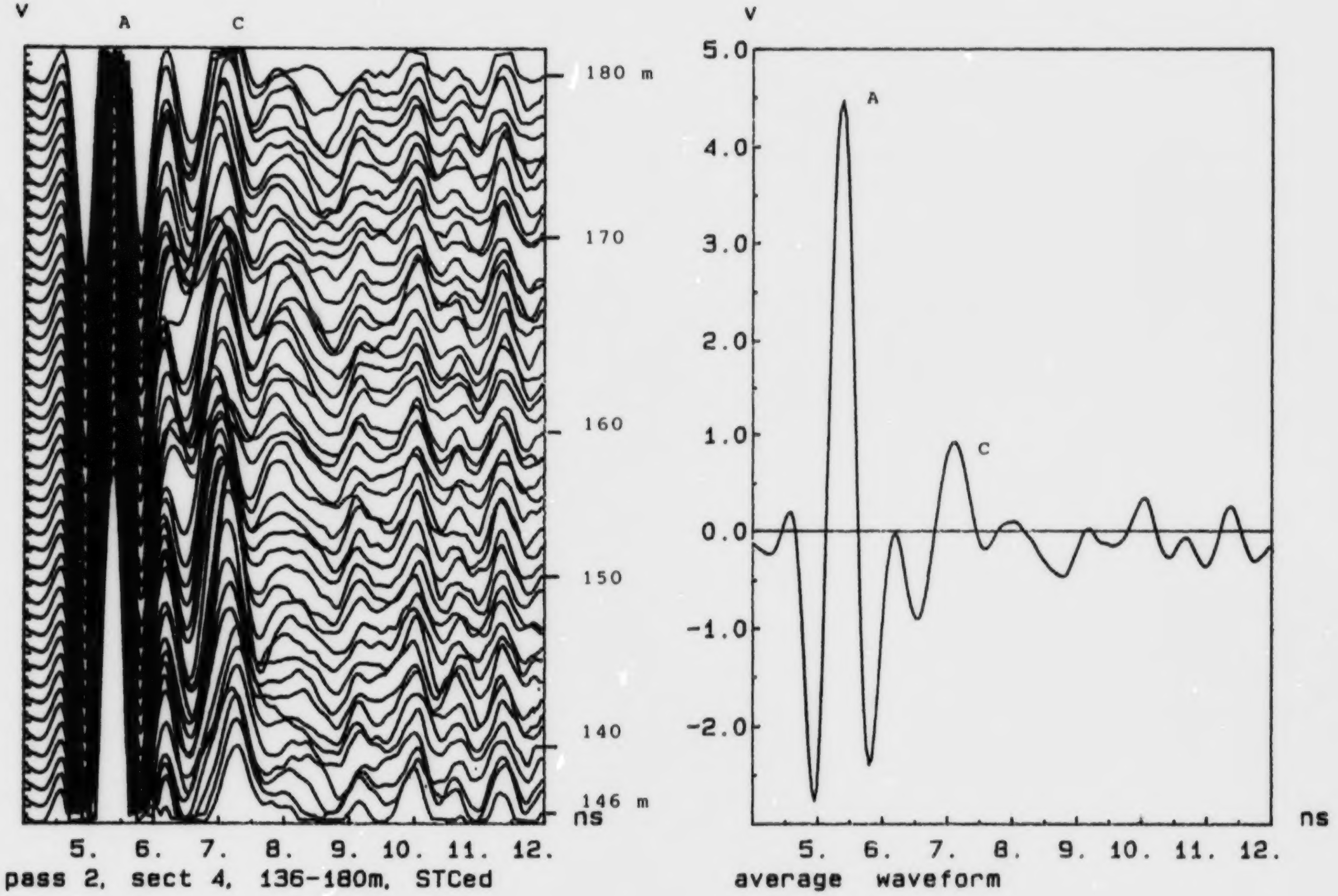


Fig 34: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (136 - 180 m).

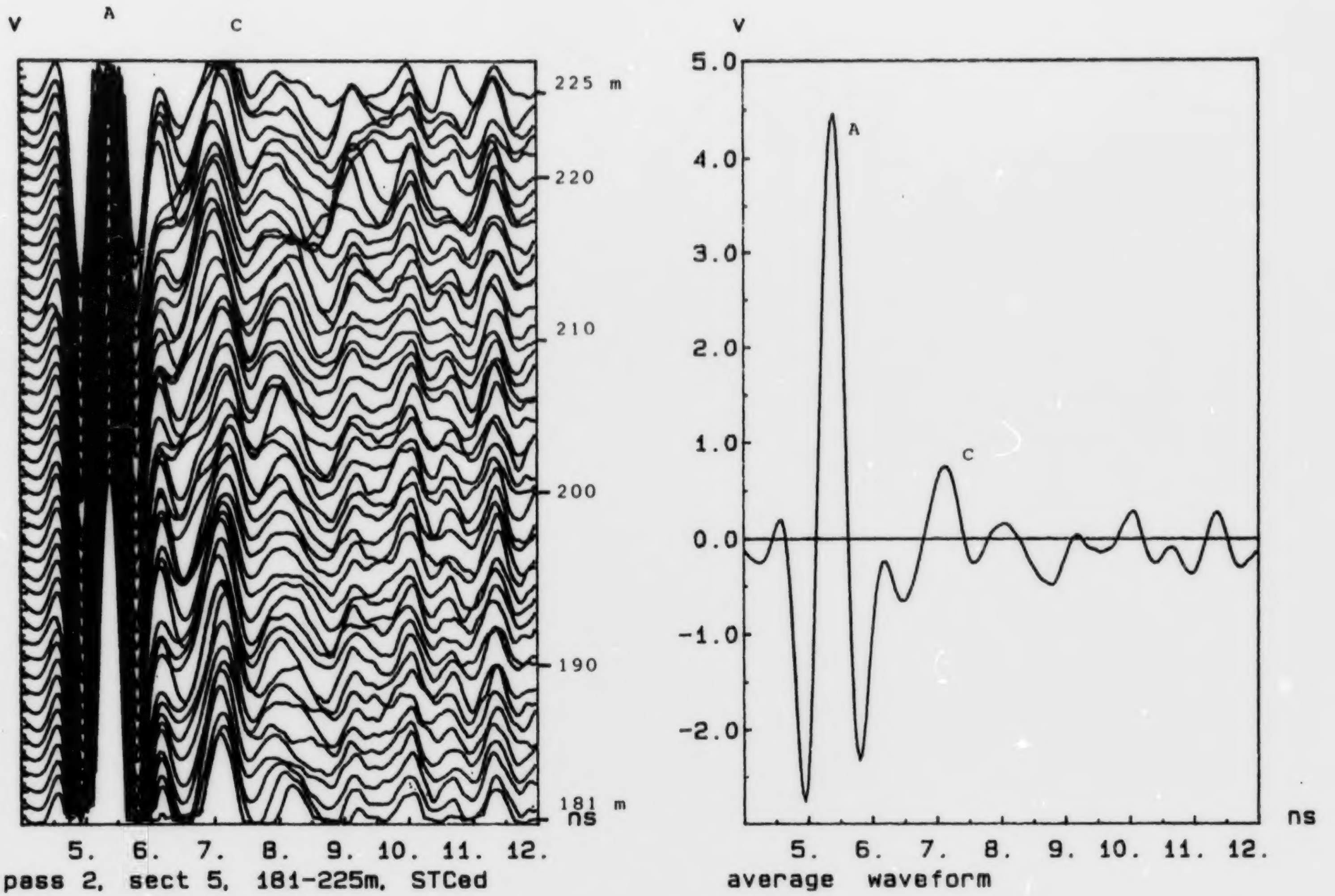


Fig 35: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (181 - 225 m).

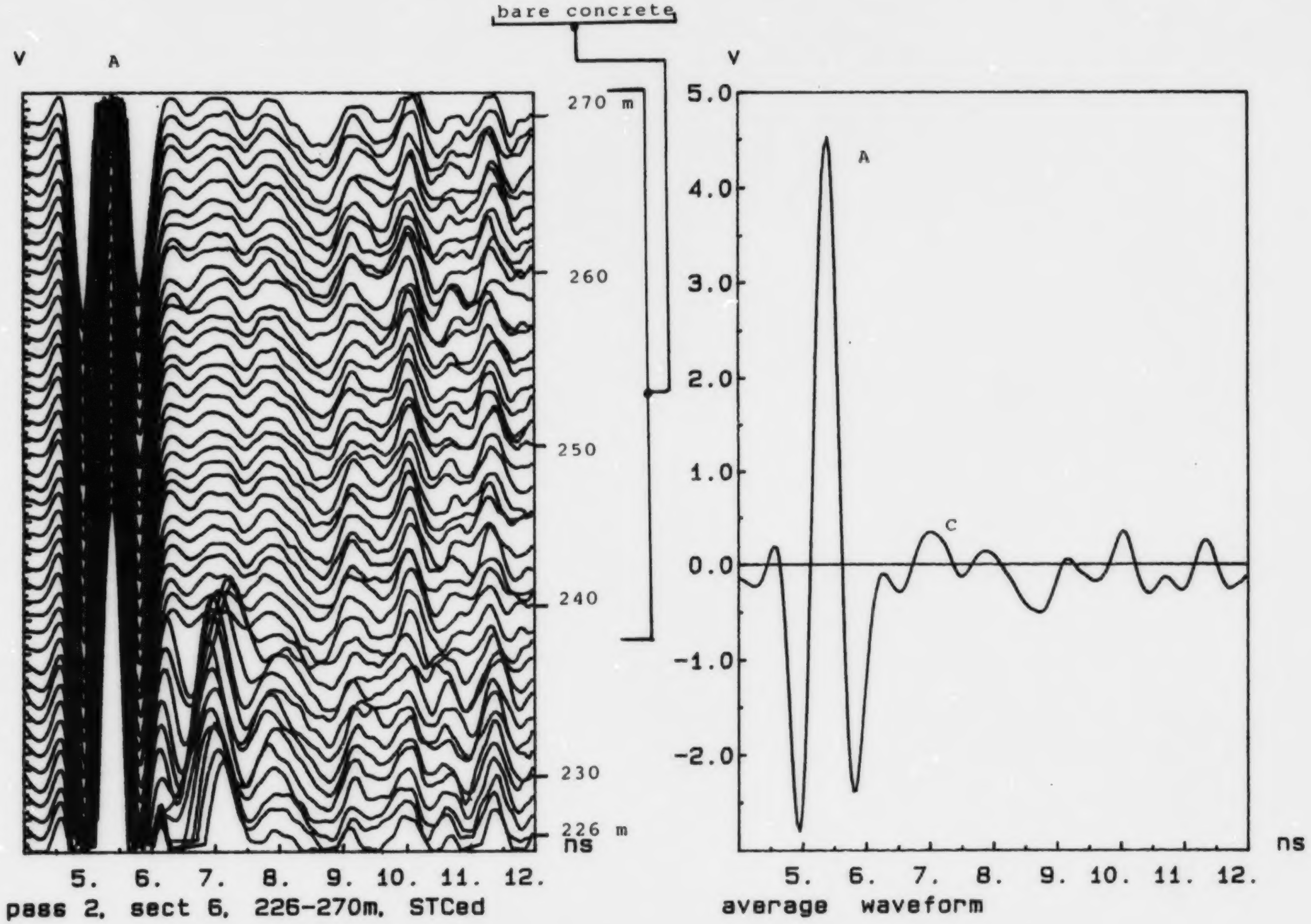


Fig 36: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (226 - 270 m).

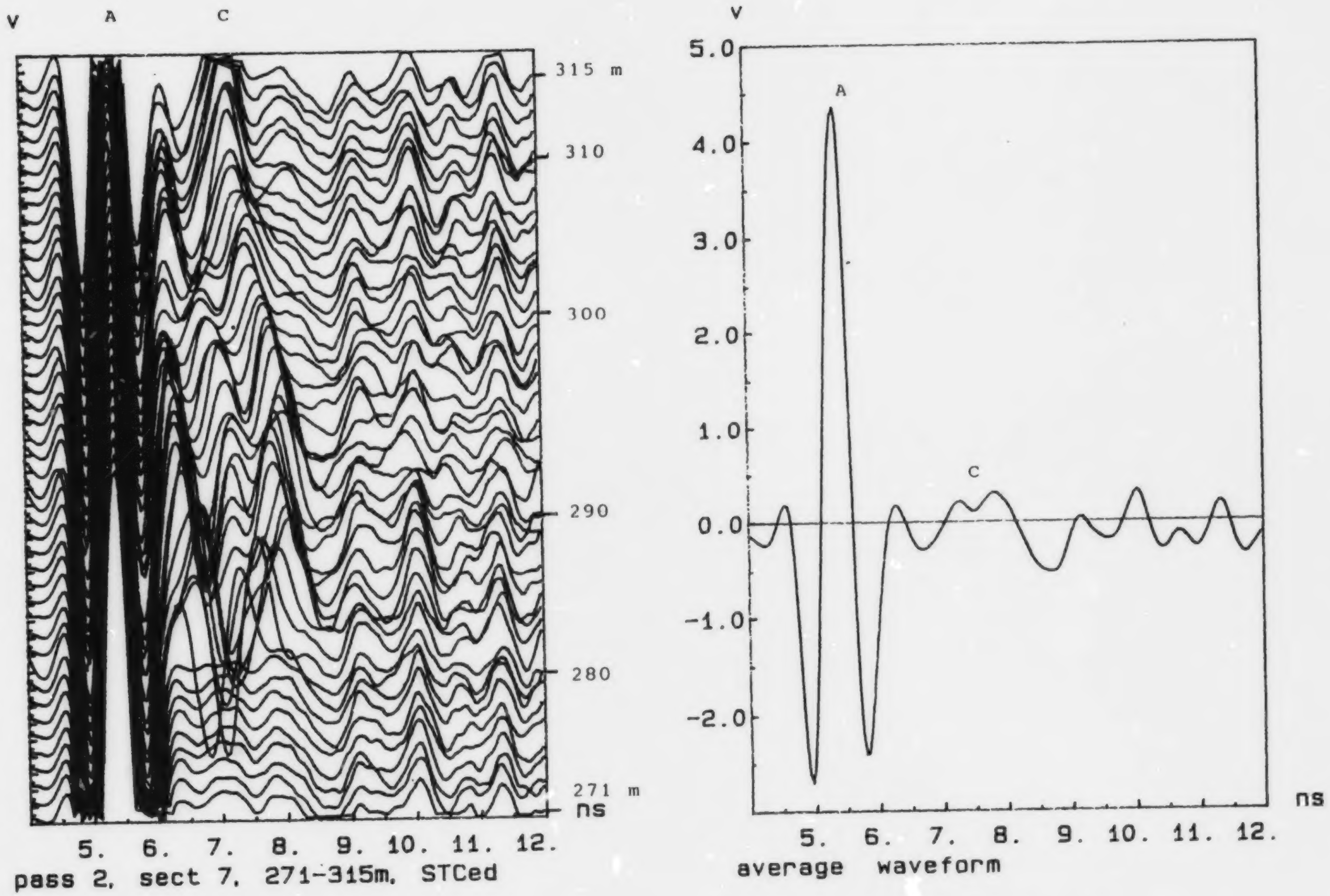


Fig 37: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (271 - 315 m).

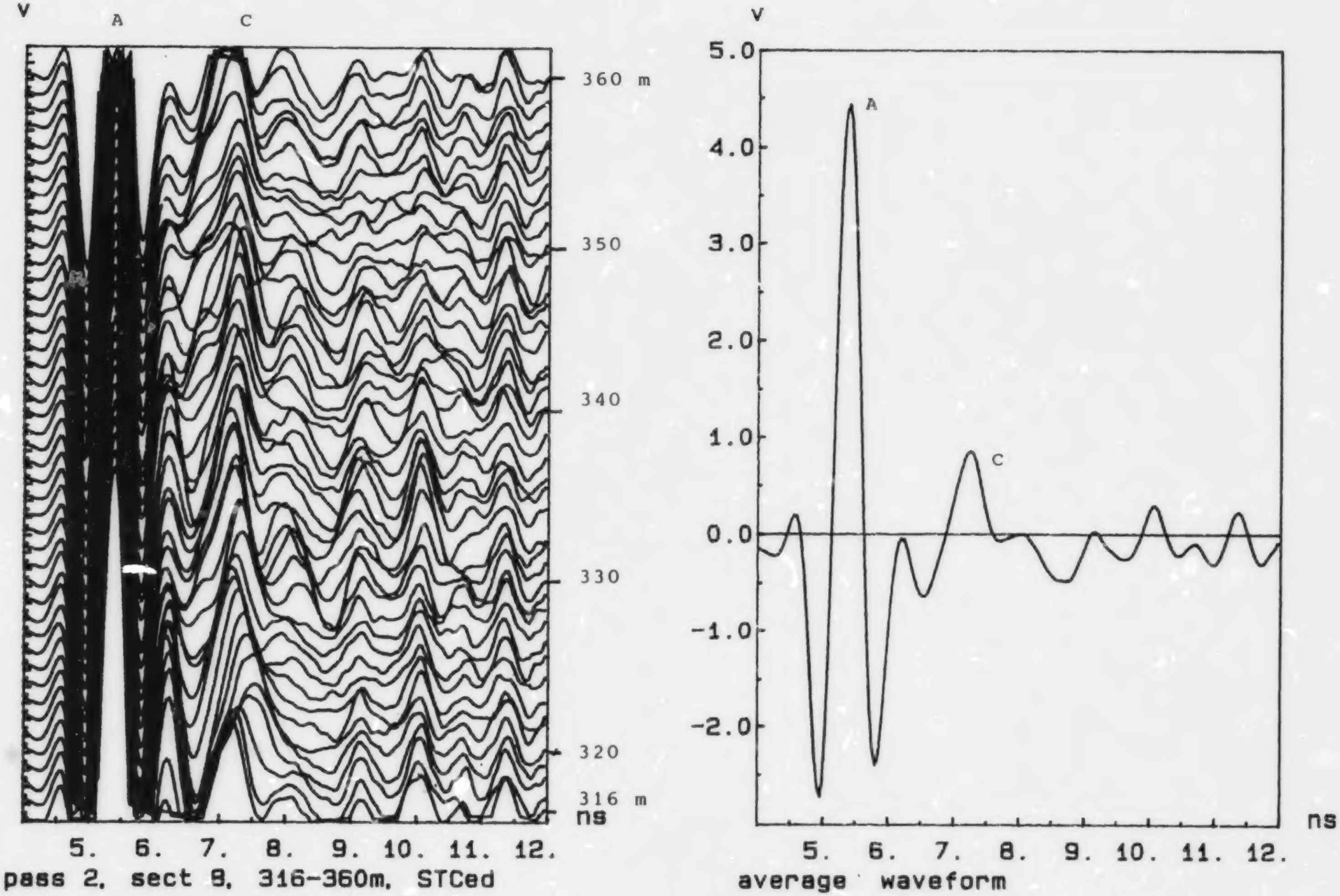


Fig 38: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (316 - 360 m).

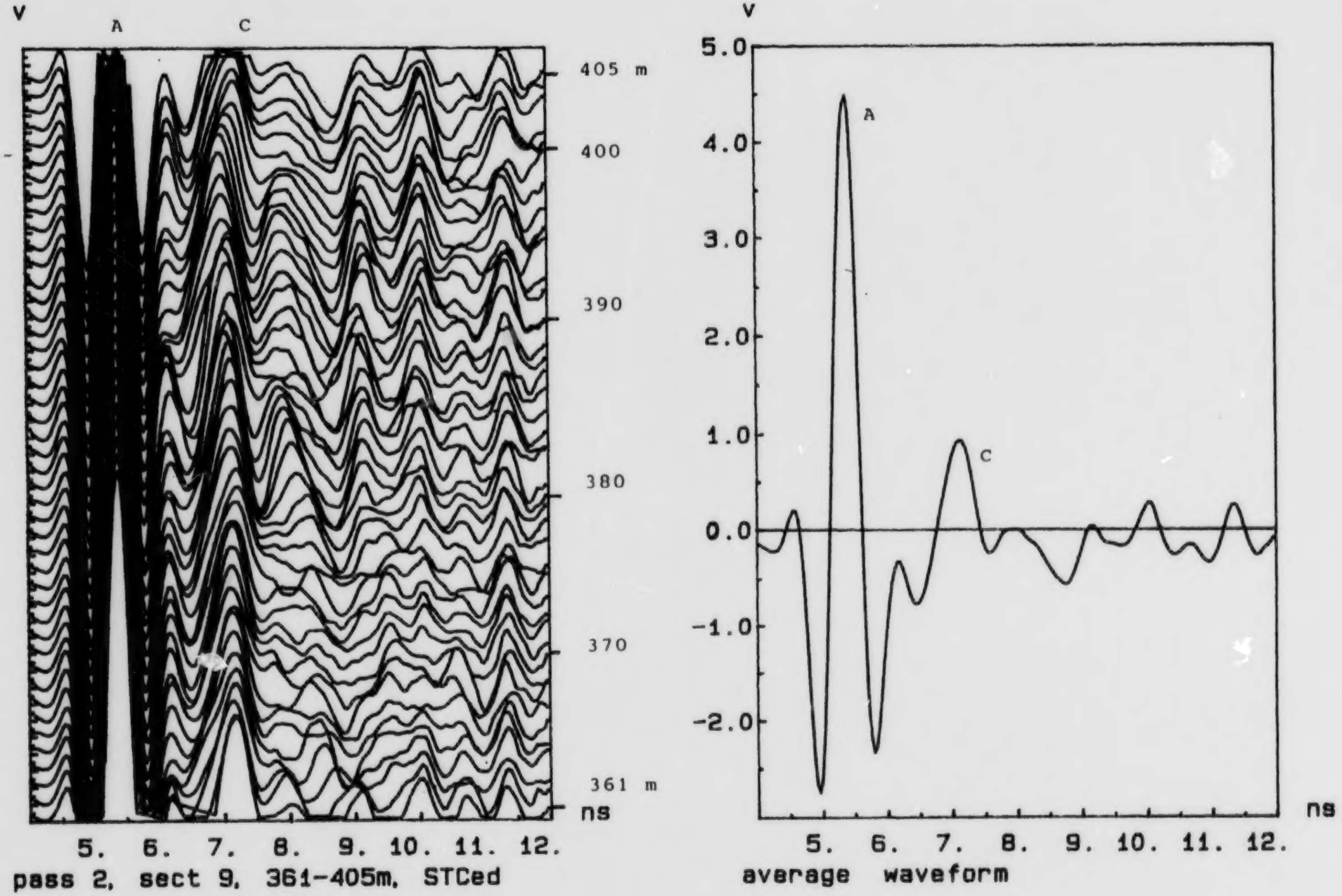


Fig 39: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (361 - 405 m).

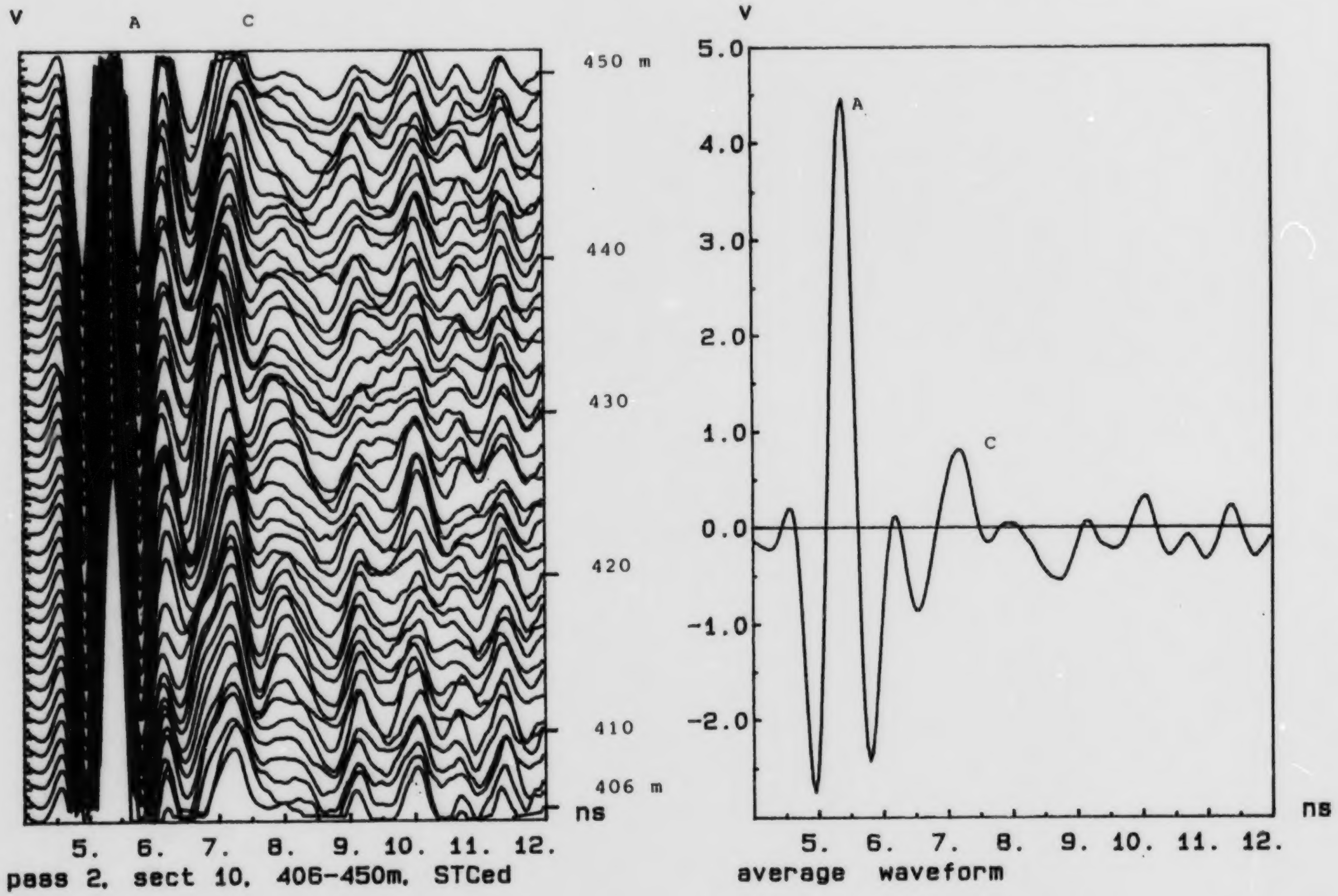


Fig 40: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (406 - 450 m).

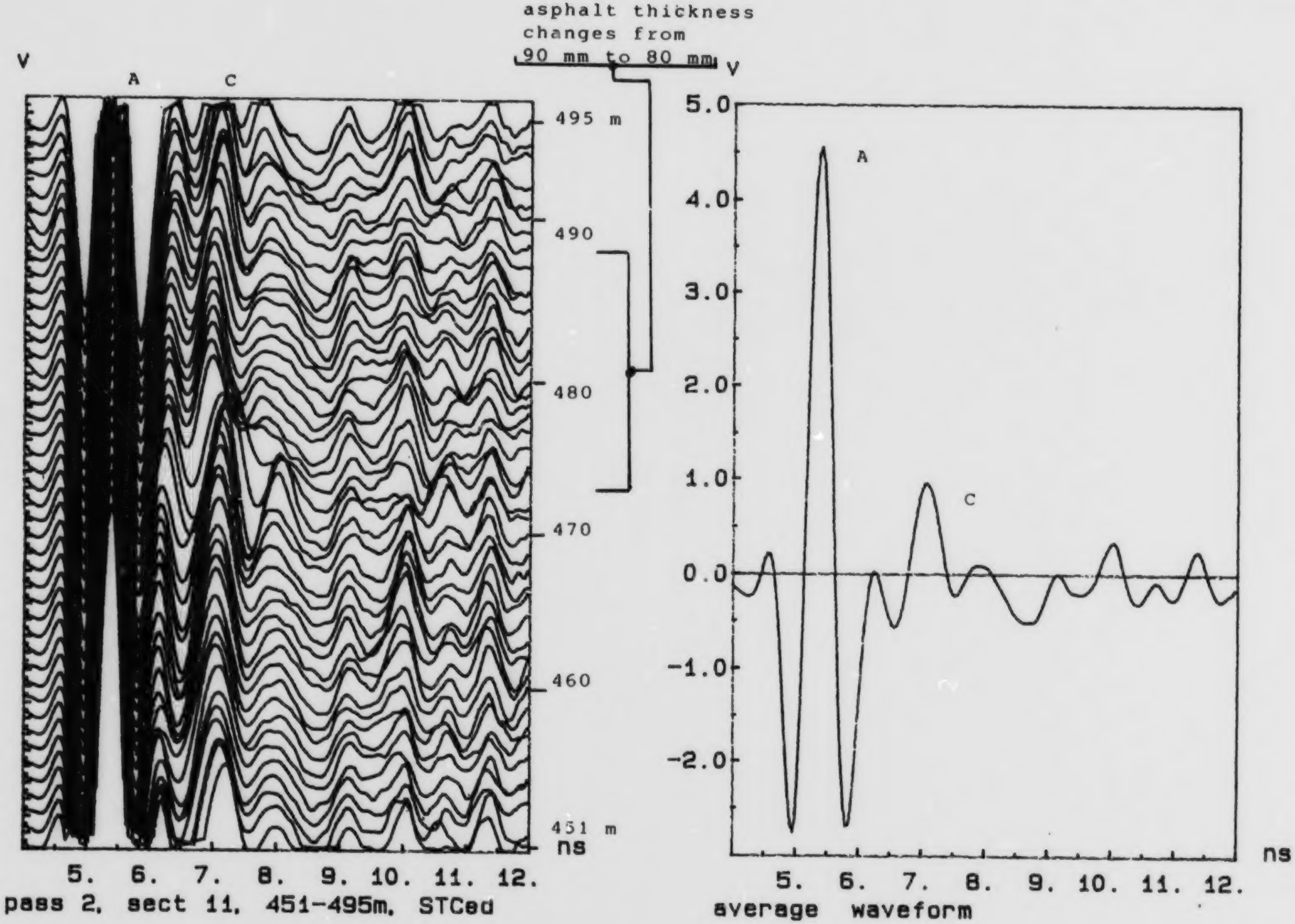


Fig 41: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (451 - 495 m).

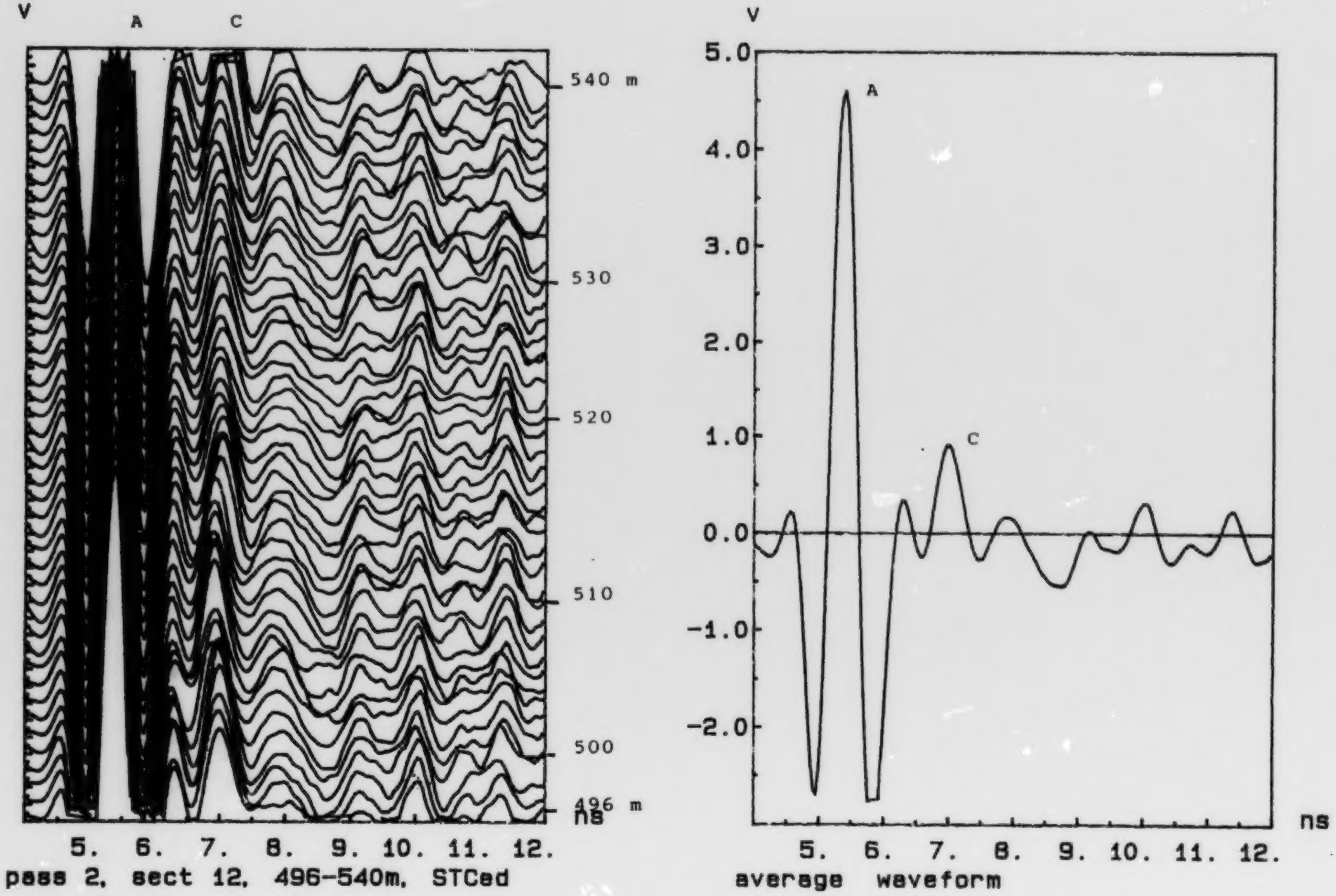


Fig 42: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (495 - 540 m).

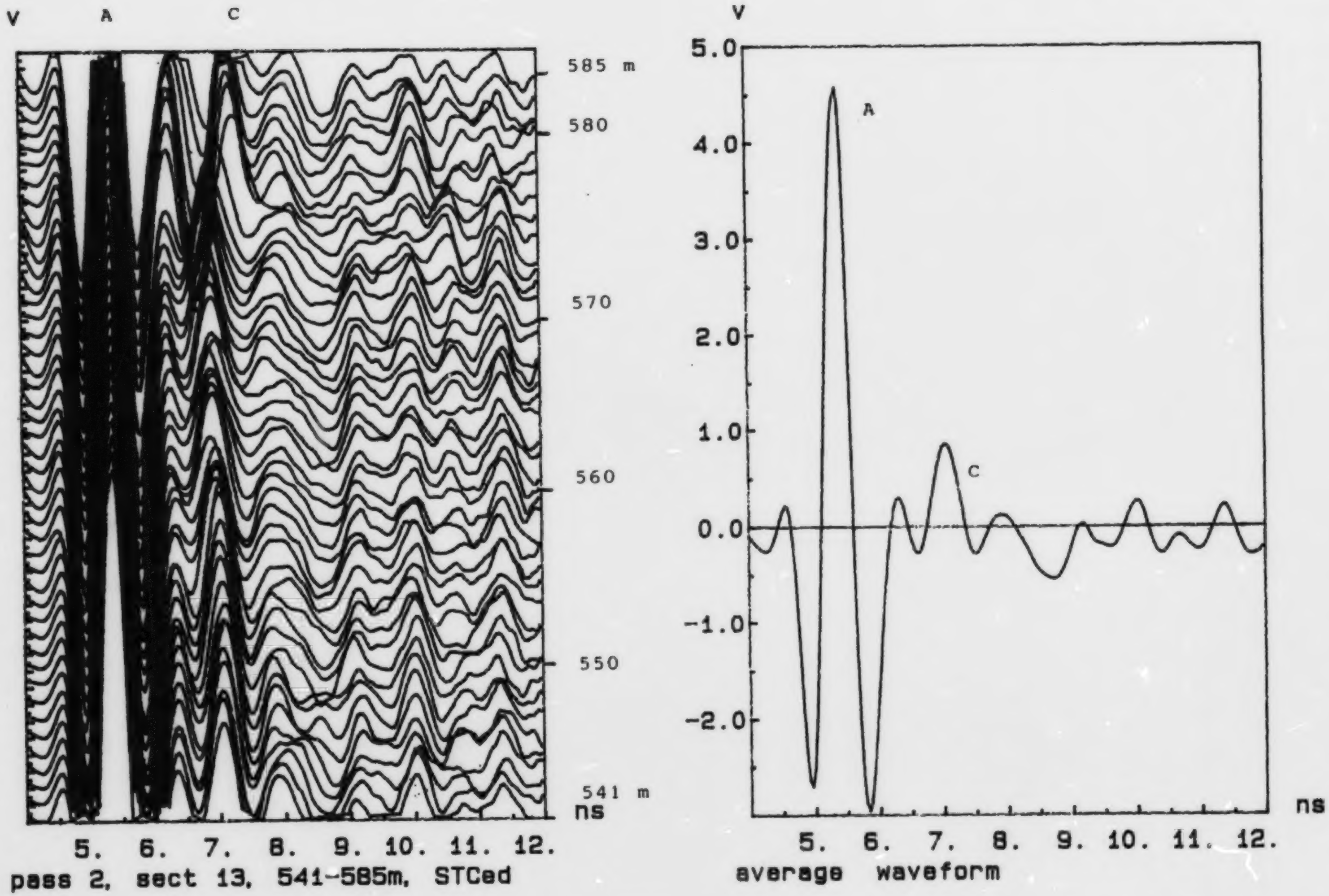


Fig 43: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (541 - 585 m).

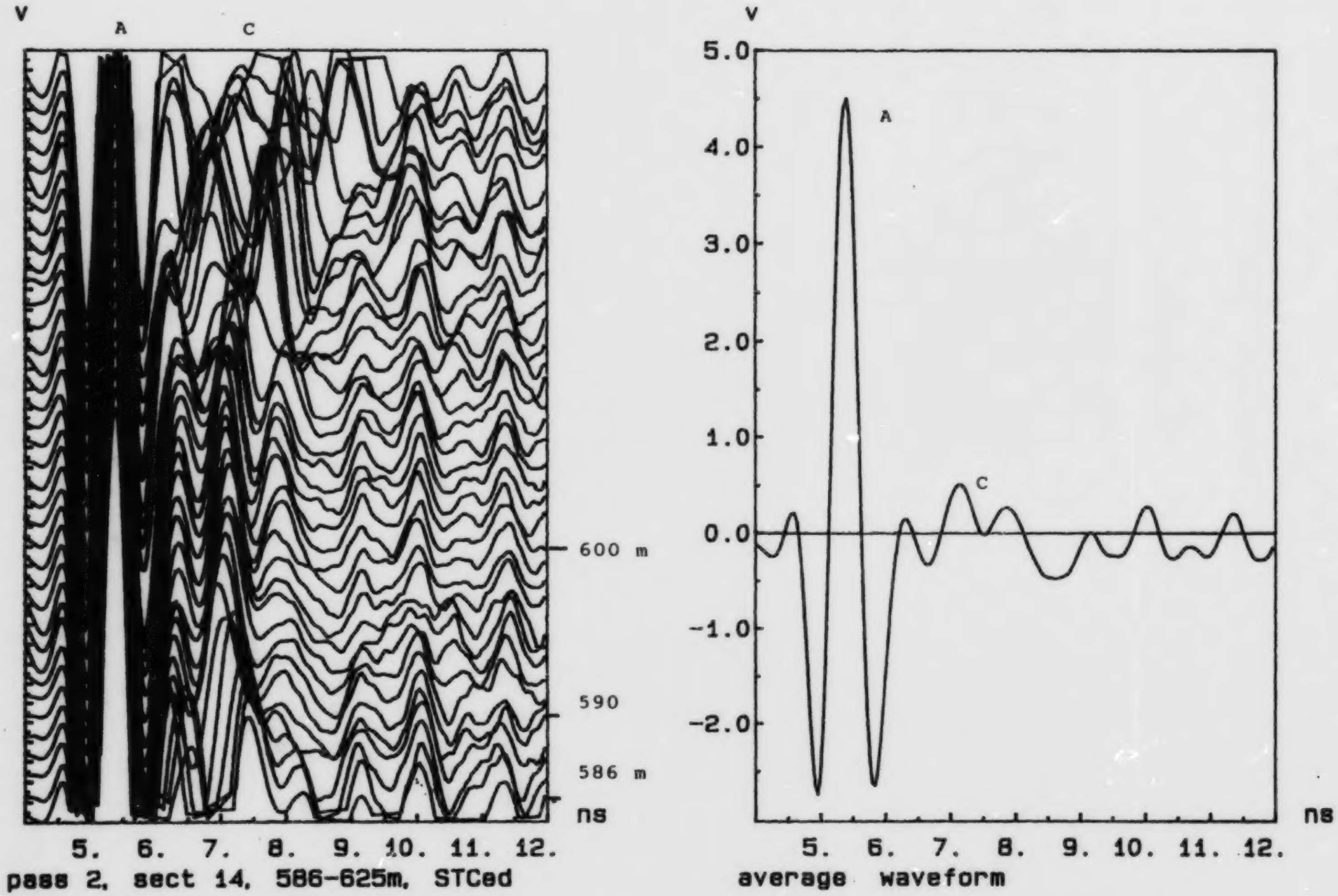
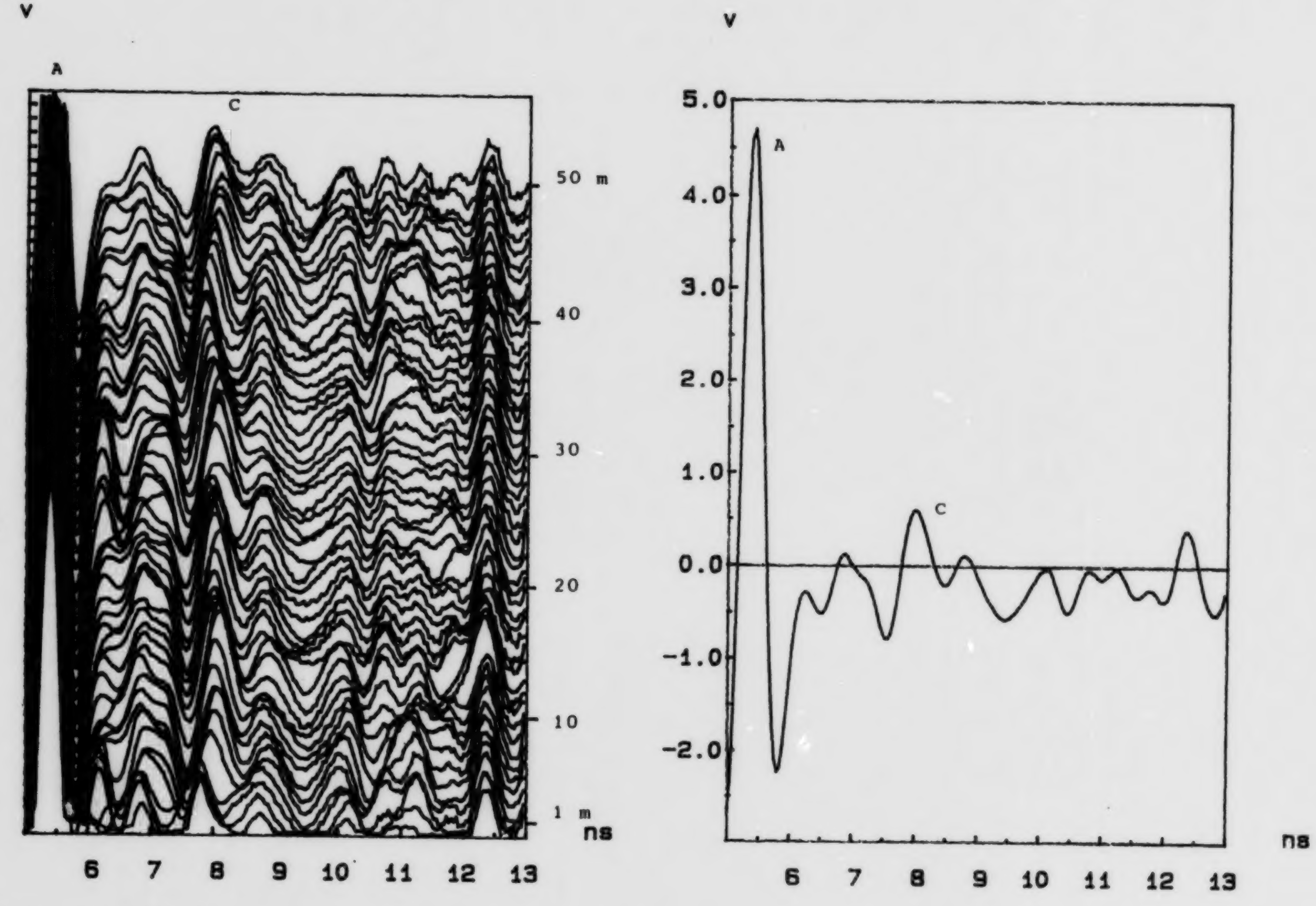


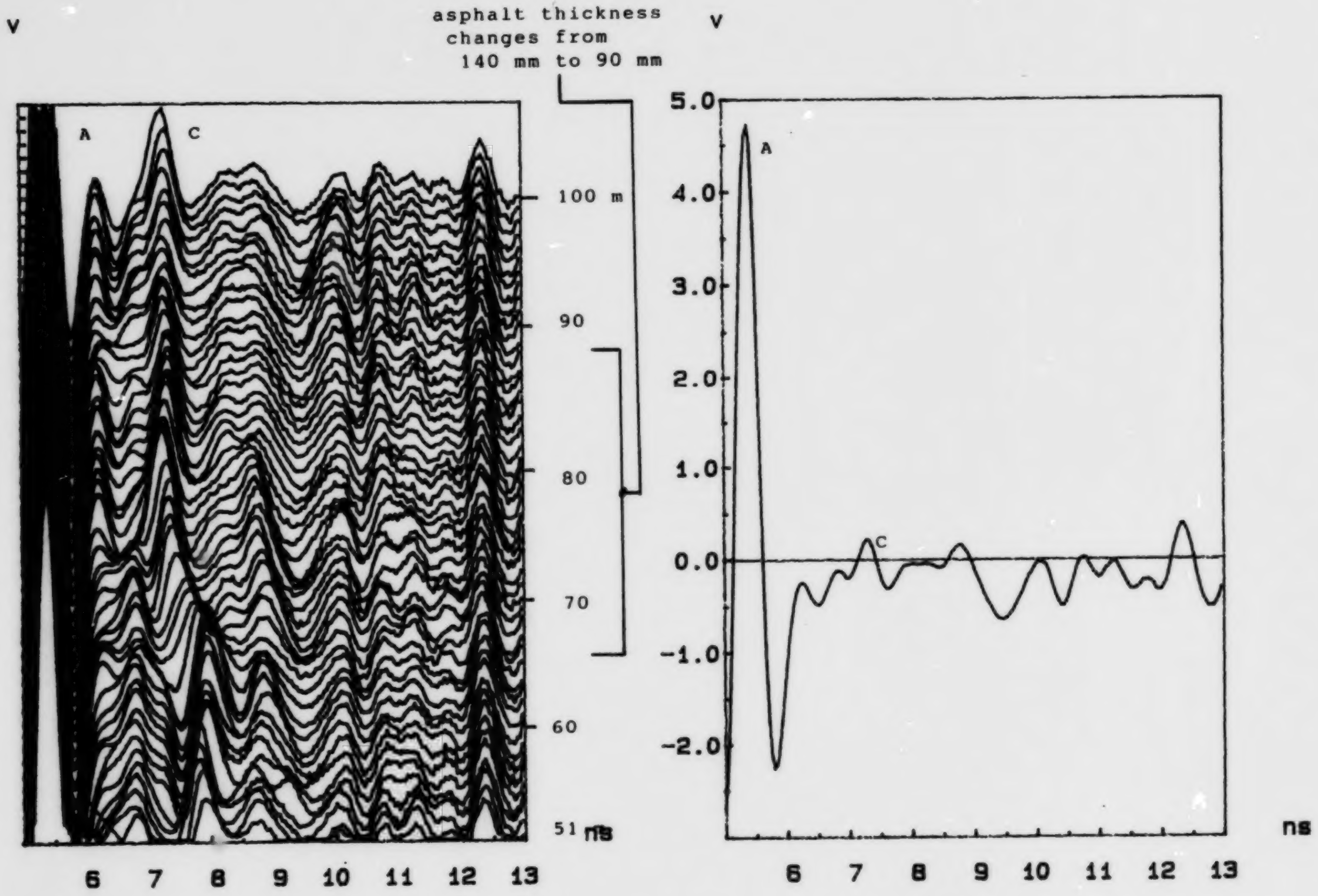
Fig 44: Hwy. 7/Dufferin (1989) - STC waveforms from Line 2 (586 - 625 m).



Hwy 7, Line 1, 1-50m

average waveform

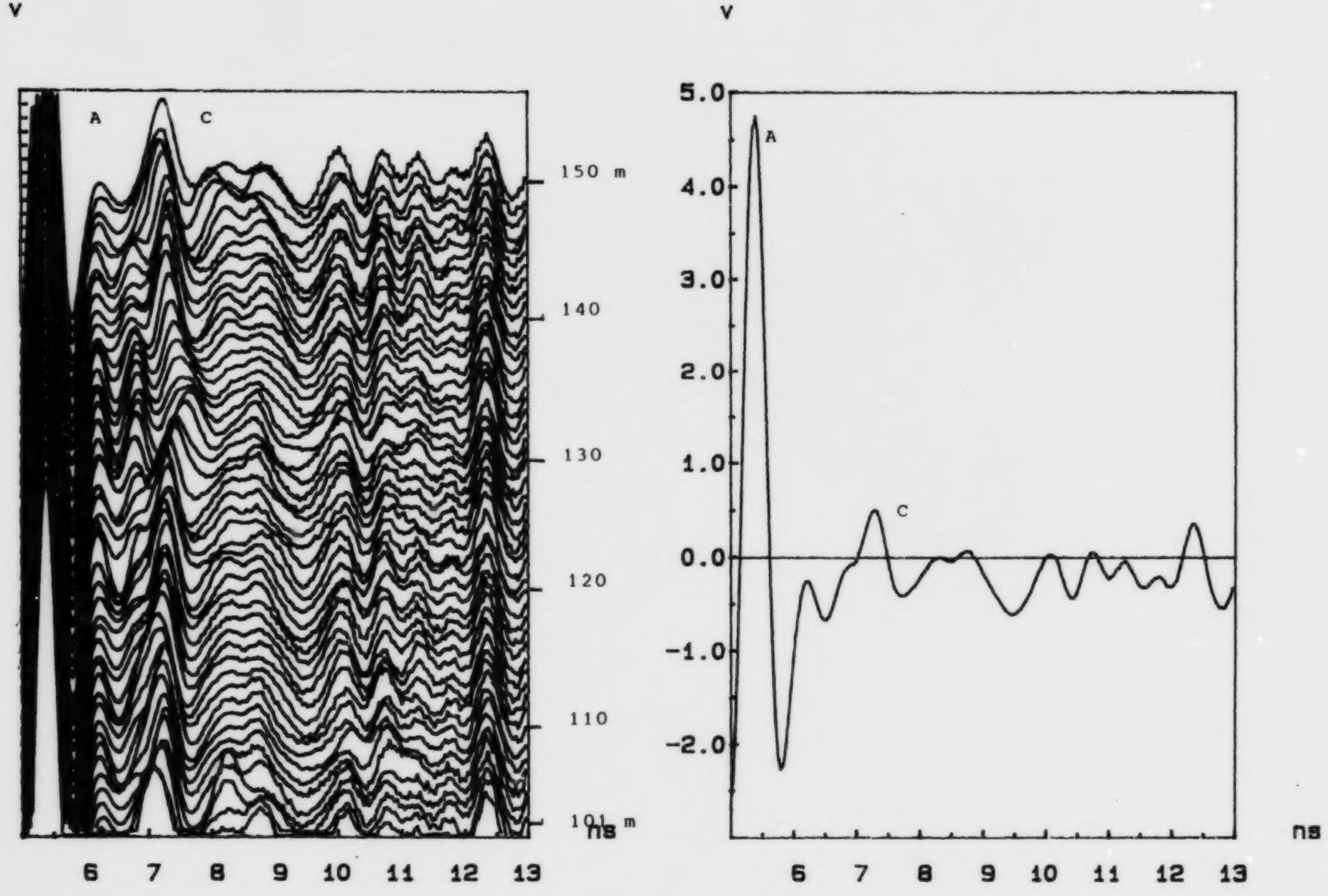
Fig 45: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (1 - 50 m).



Hwy 7. Line 1. 51-100m

average waveform

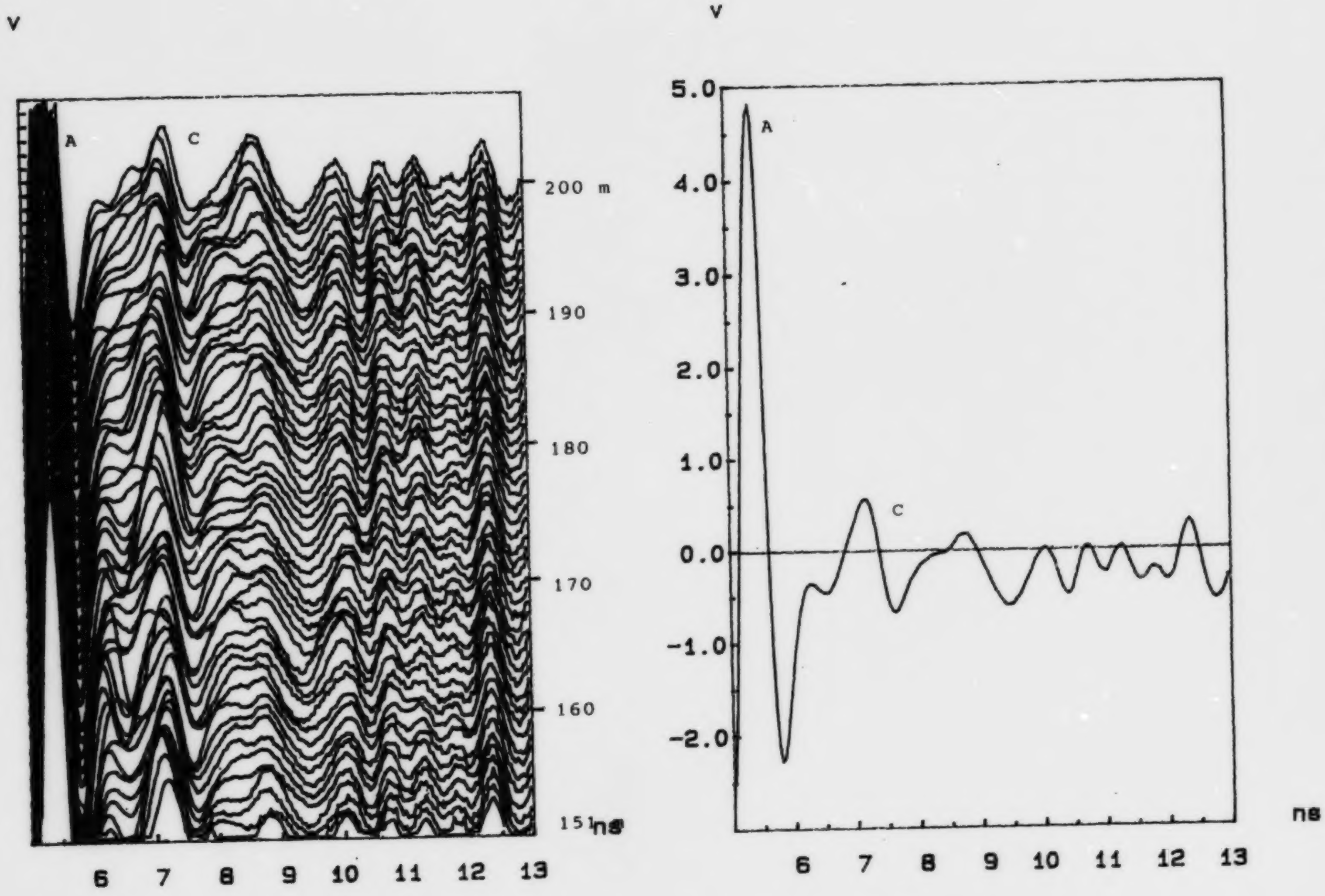
Fig 46: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (51 - 100 m).



Hwy 7. Line 1. 101-150m

average waveform

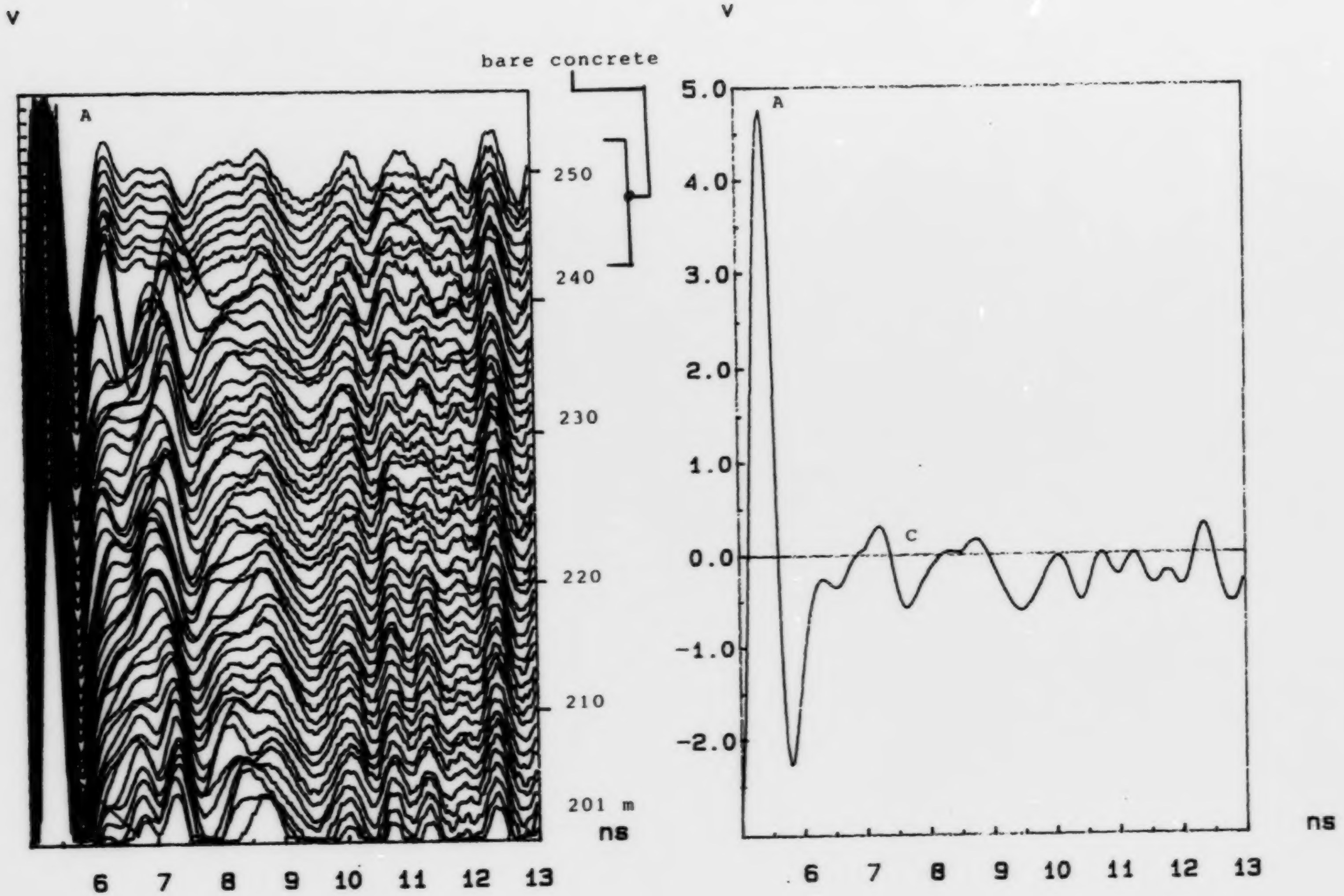
Fig 47: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (101 - 150 m).



Hwy 7. Line 1. 151-200m

average waveform

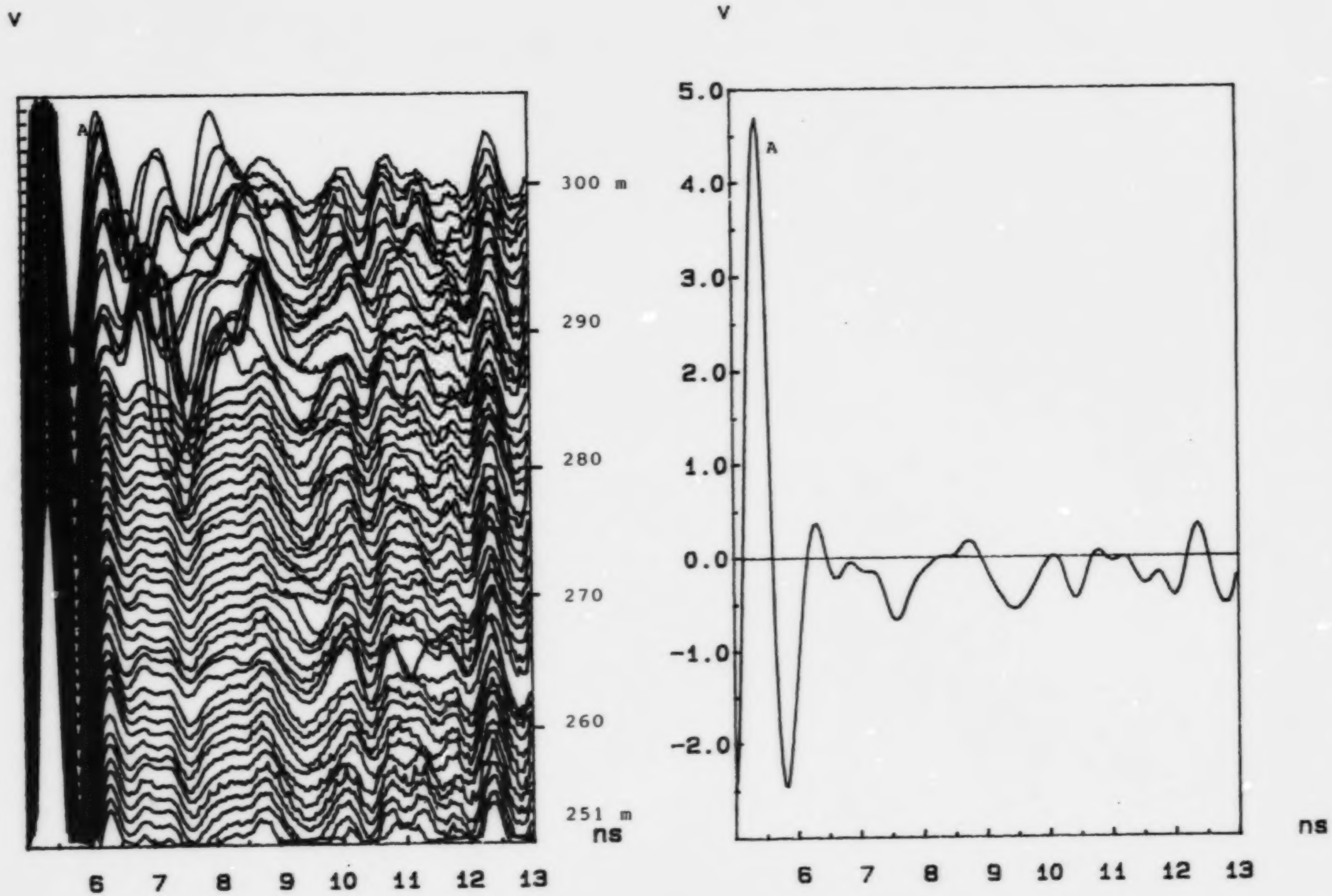
Fig 48: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (151 - 200 m).



Hwy 7. Line 1. 201-250m

average waveform

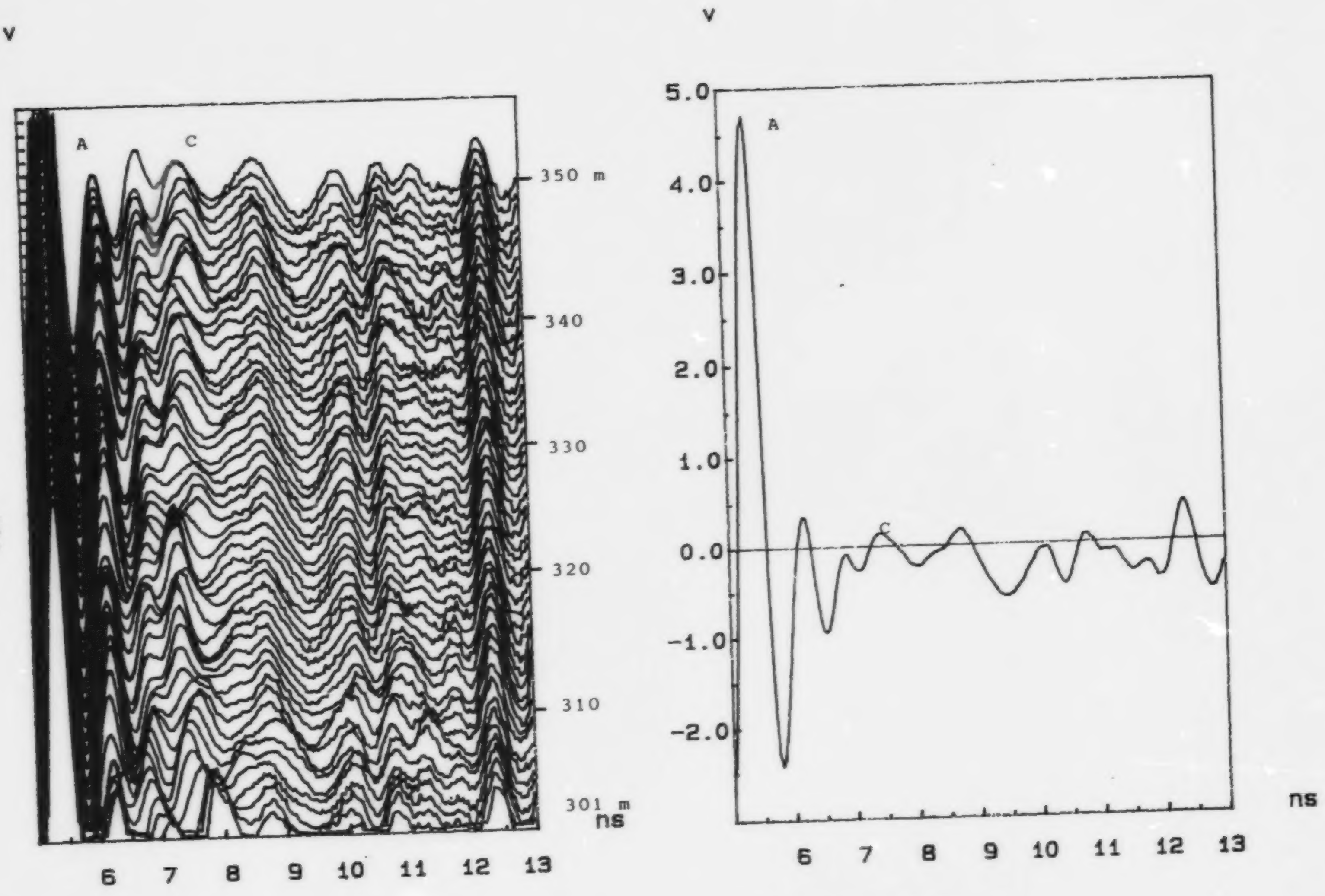
Fig 49: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (201 - 250 m).



Hwy 7. Line 1. 251-300m

average waveform

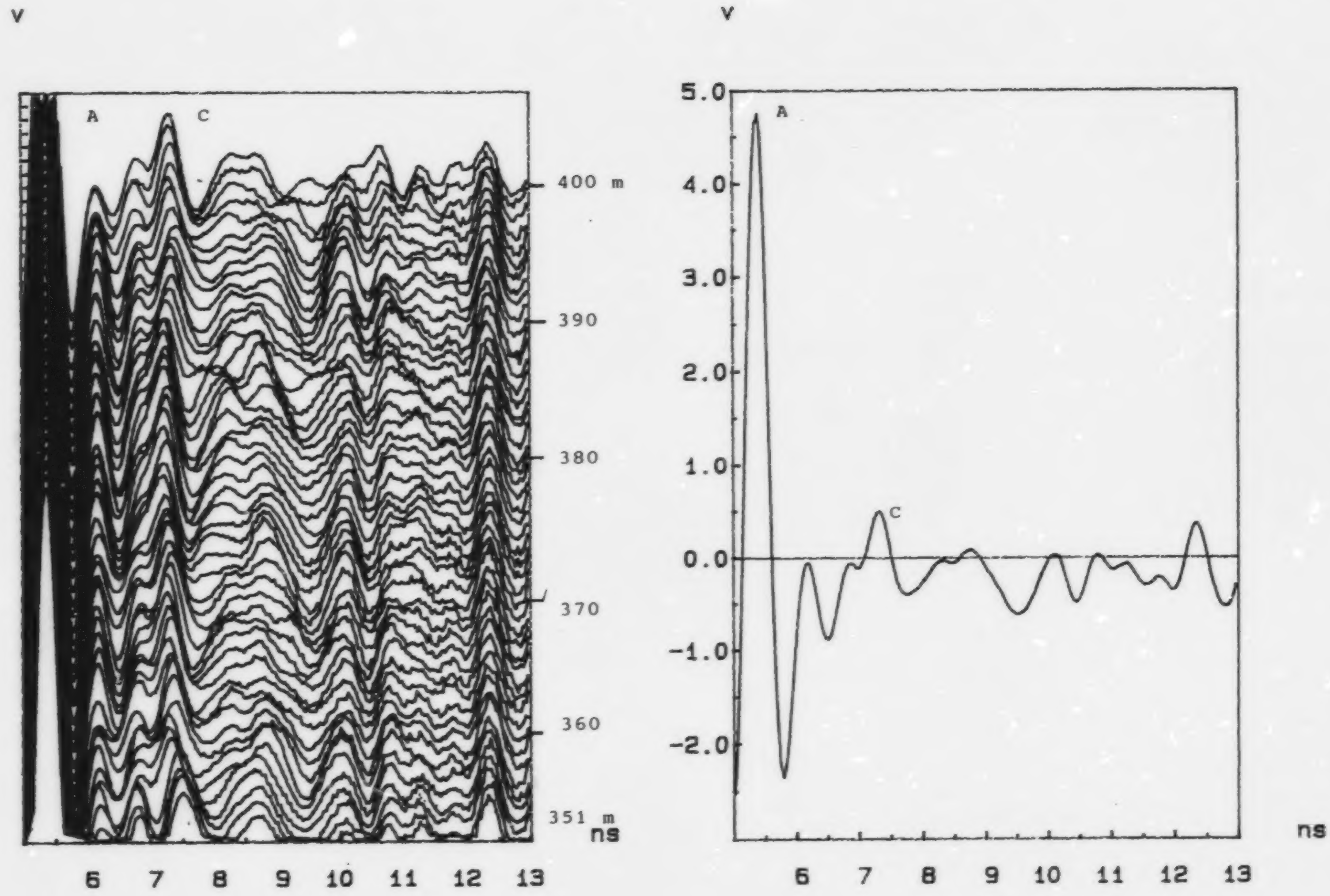
Fig 50: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (251 - 300 m).



Hwy 7. Line 1. 301-350m

average waveform

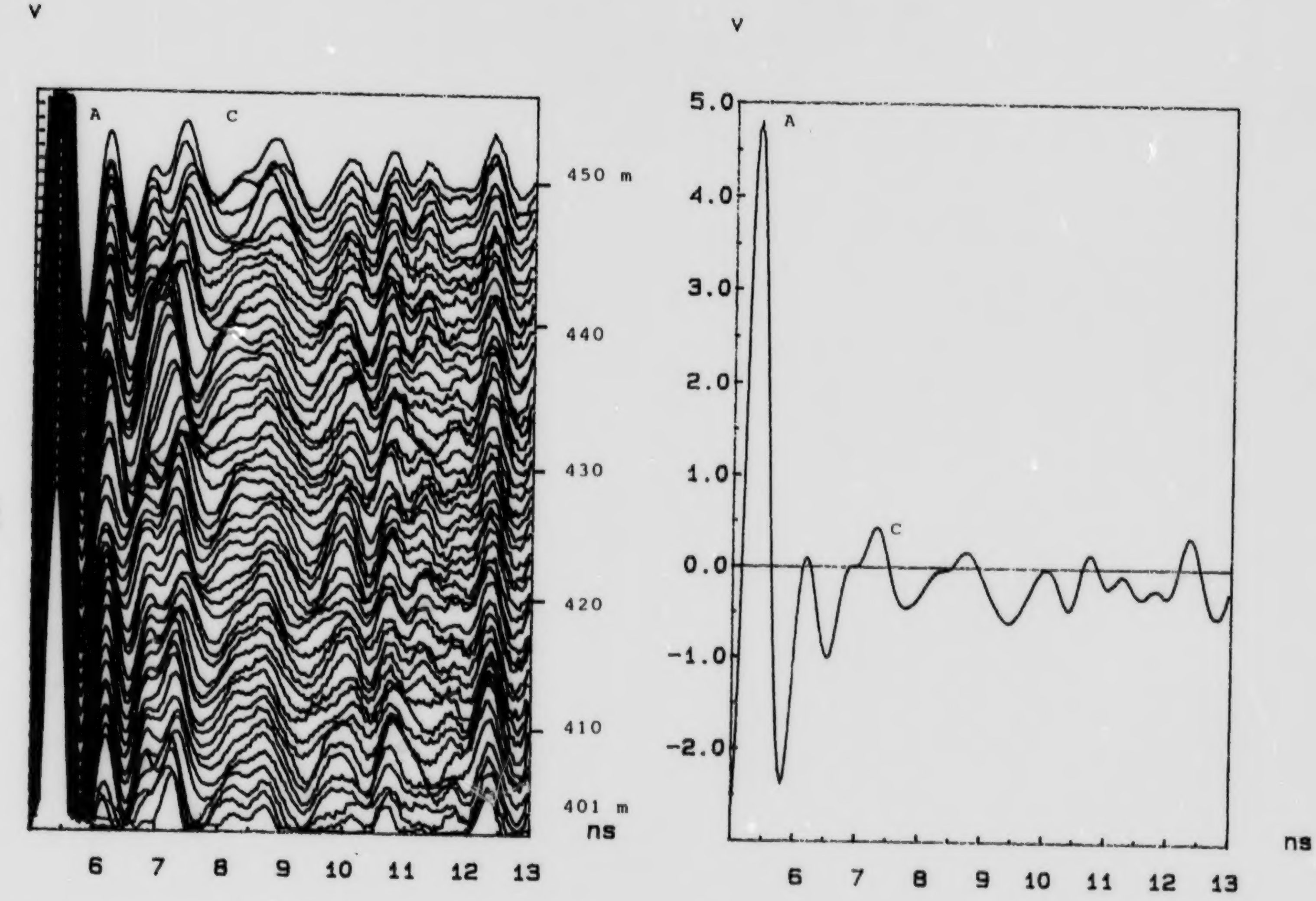
Fig 51: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (301 - 350 m).



Hwy 7. Line 1. 351-400m

average waveform

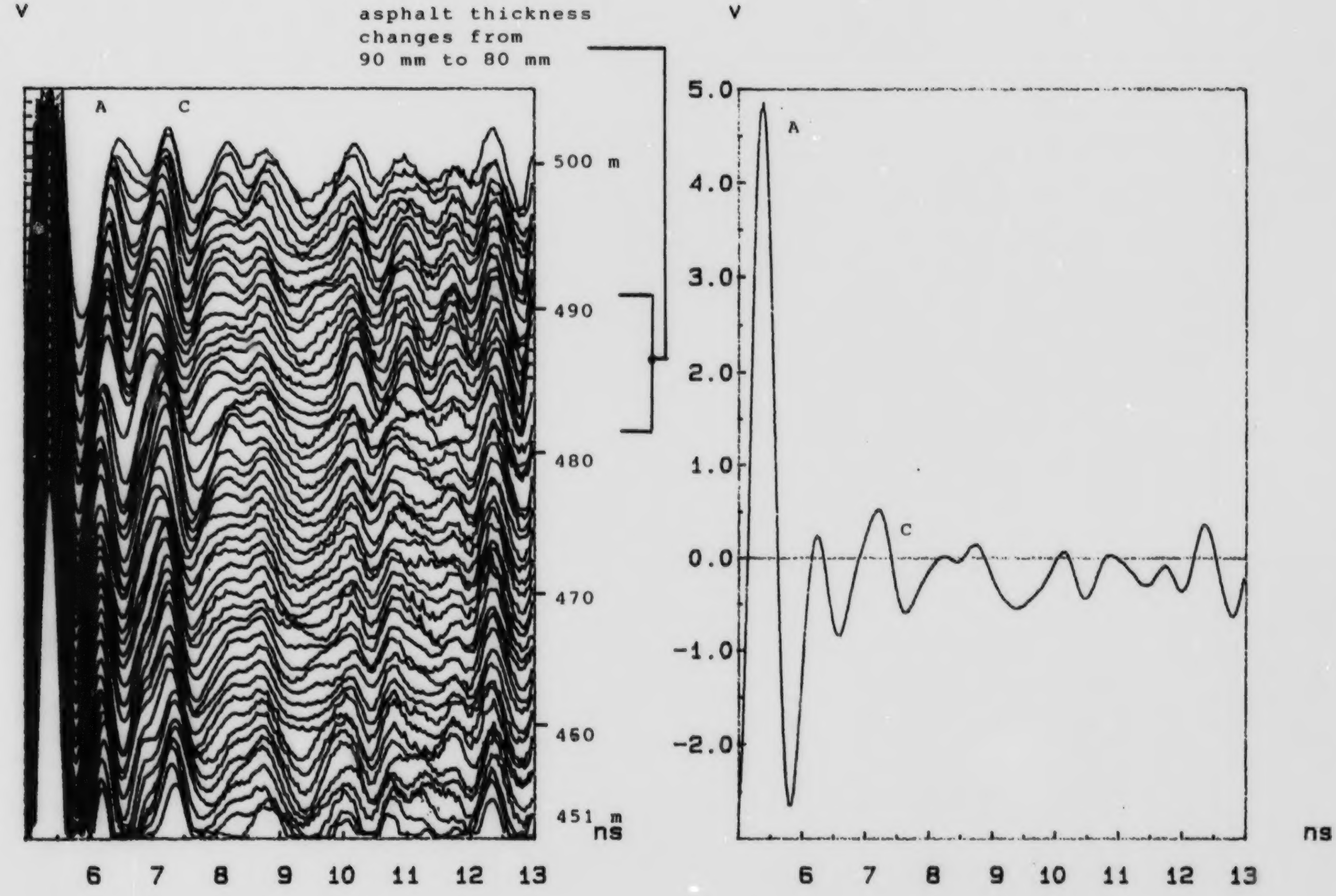
Fig 52: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (351 - 400 m).



Hwy 7. Line 1. 401-450m

average waveform

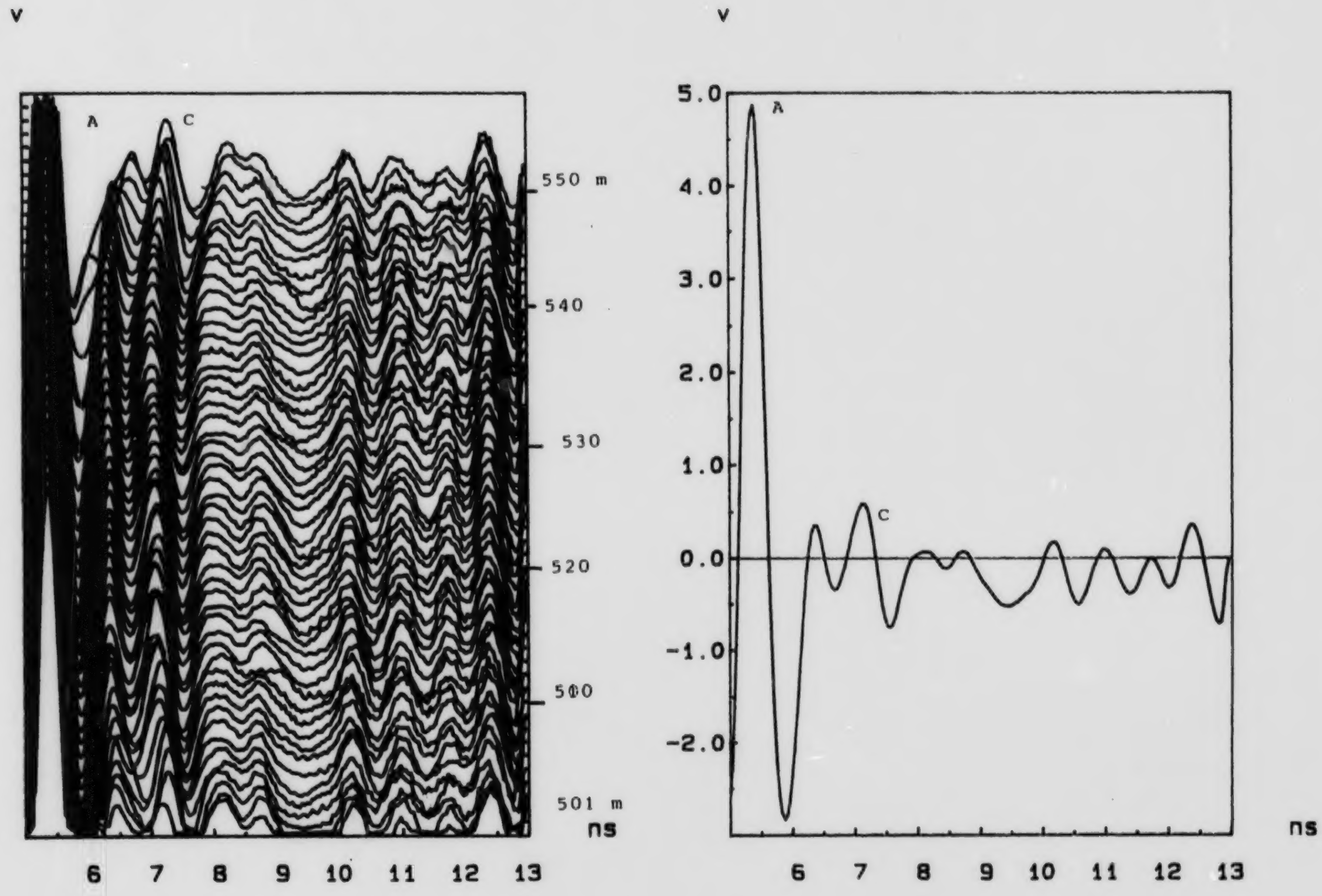
Fig 53: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (401 - 450 m).



Hwy 7. Line 1. 451-500m

average waveform

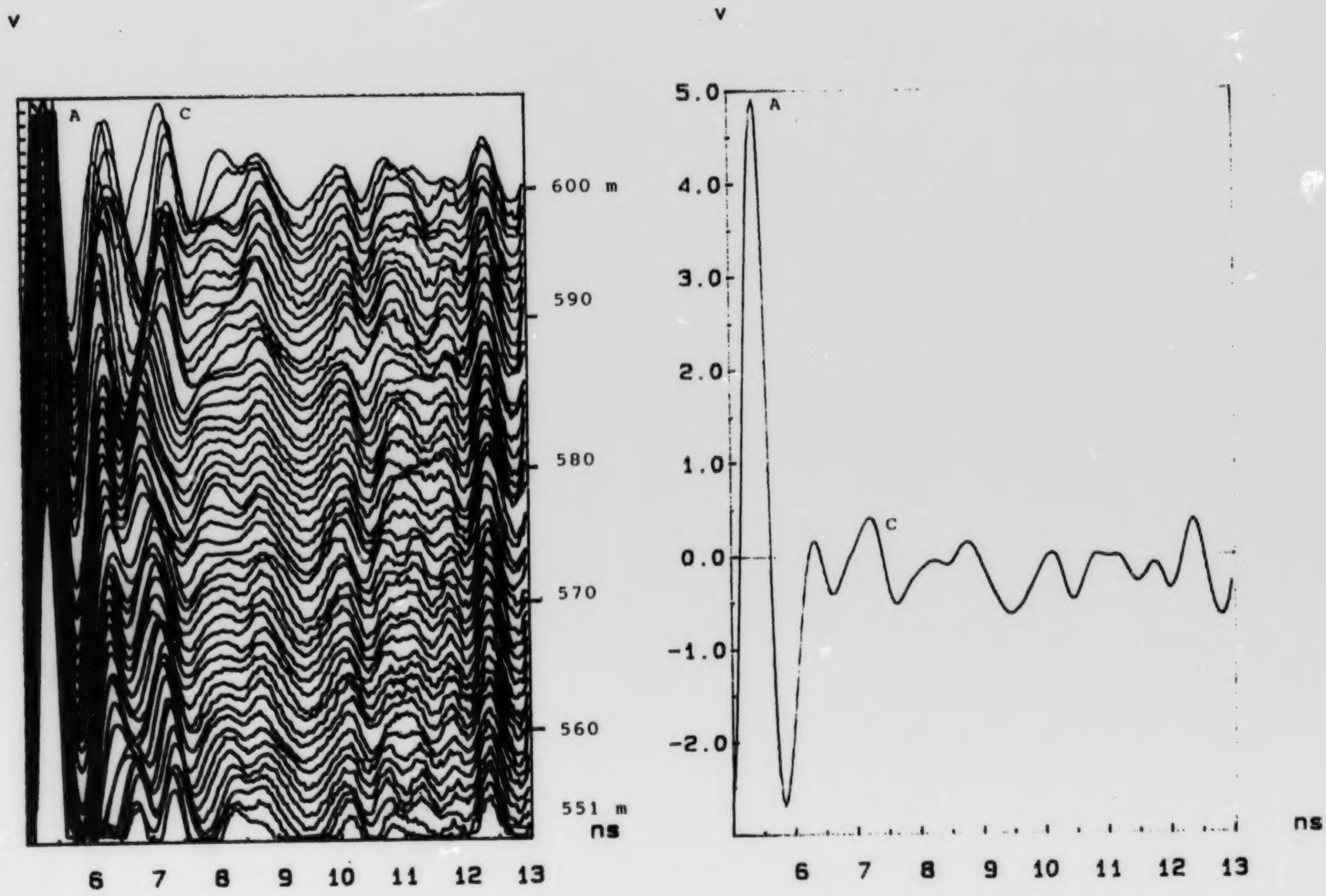
Fig 54: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (451 - 500 m).



Hwy 7. Line 1, 501-550m

average waveform

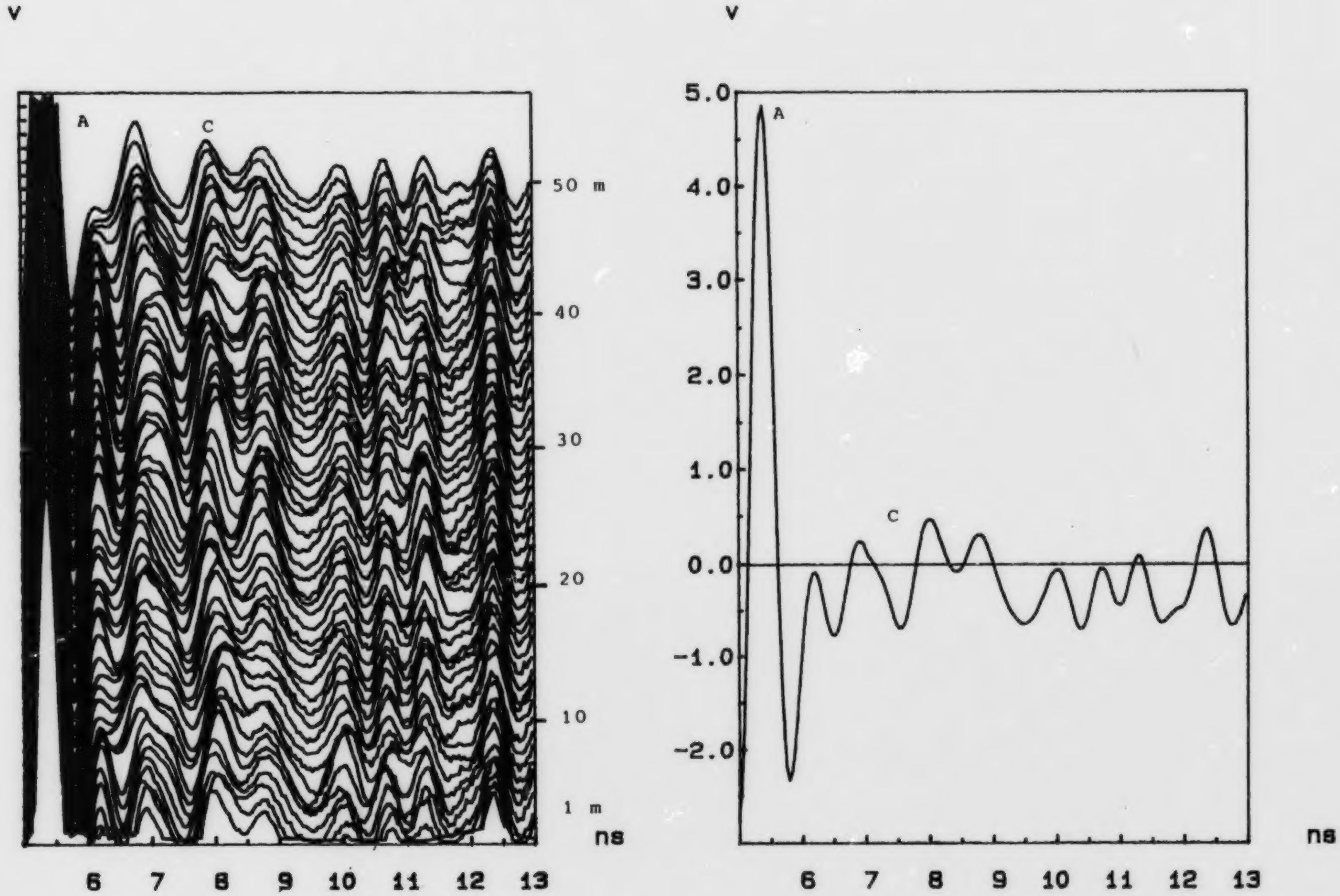
Fig 55: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (501 - 550 m).



Hwy 7. Line 1. 551-600m

average waveform

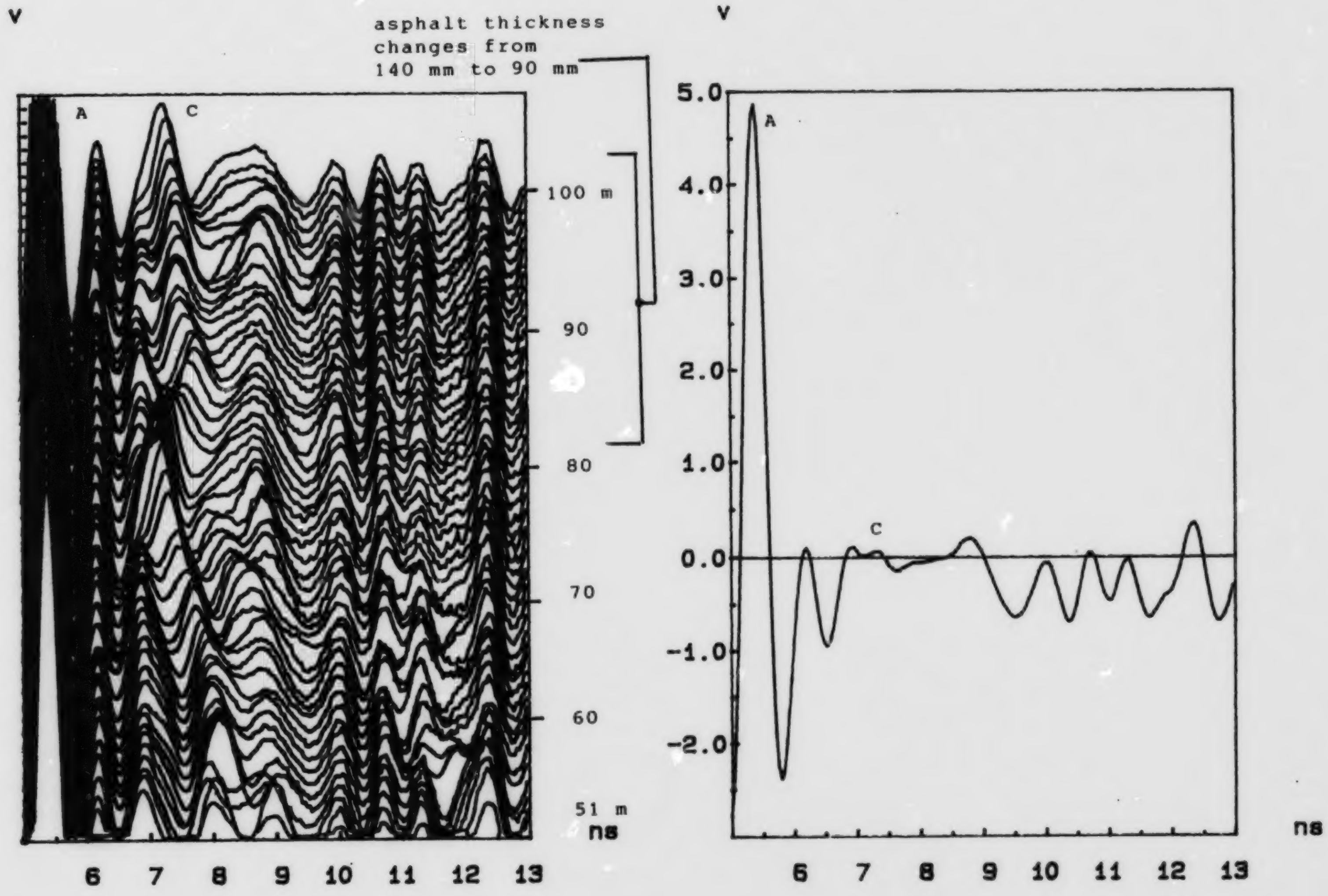
Fig 56: Hwy. 7/Dufferin (1990) - STC waveforms from Line 1 (551 - 600 m).



Hwy 7, line 2, 1-50m

average waveform

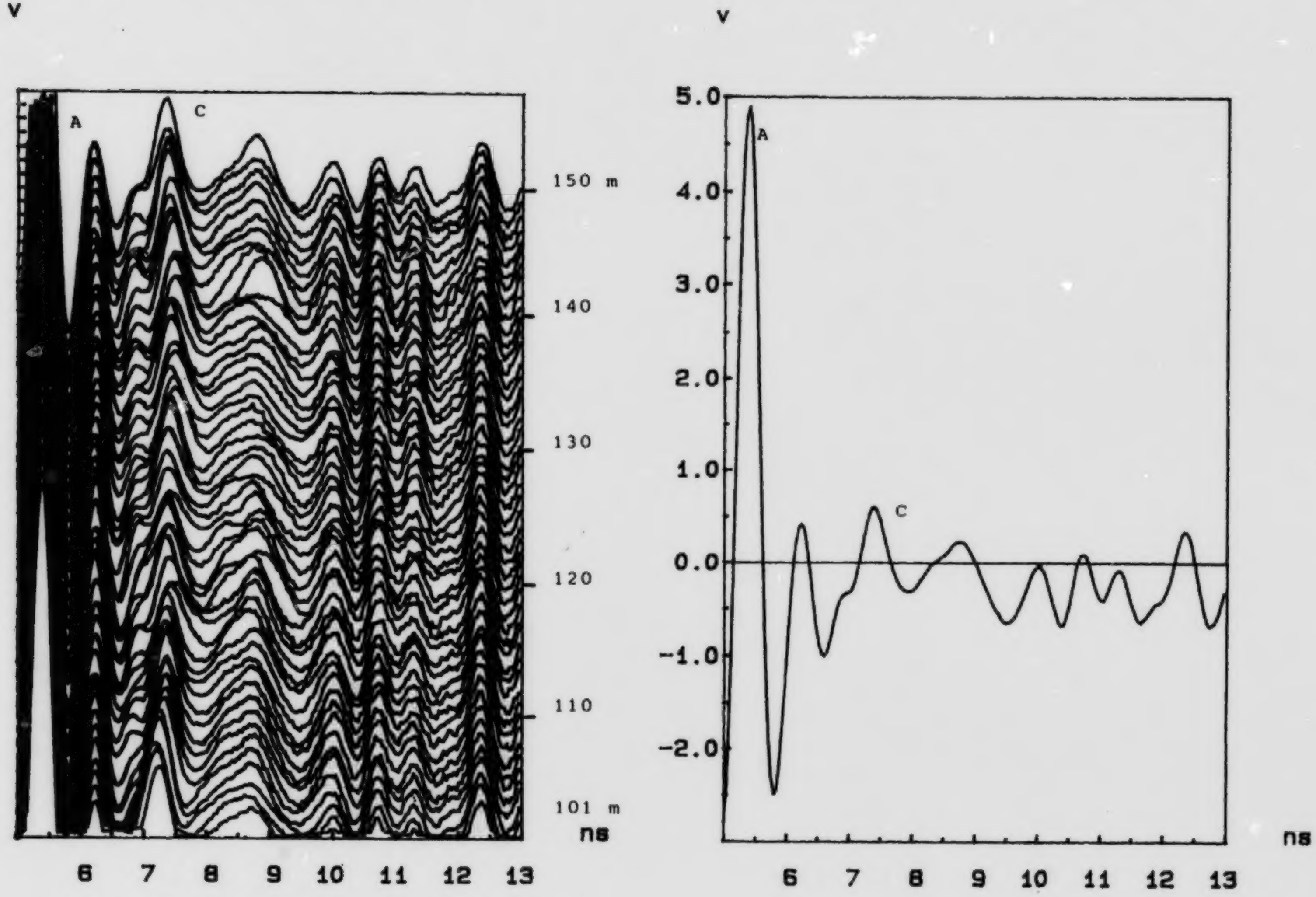
Fig 57: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (1 - 50 m).



Hwy 7. Line 2. 51-100m

average waveform

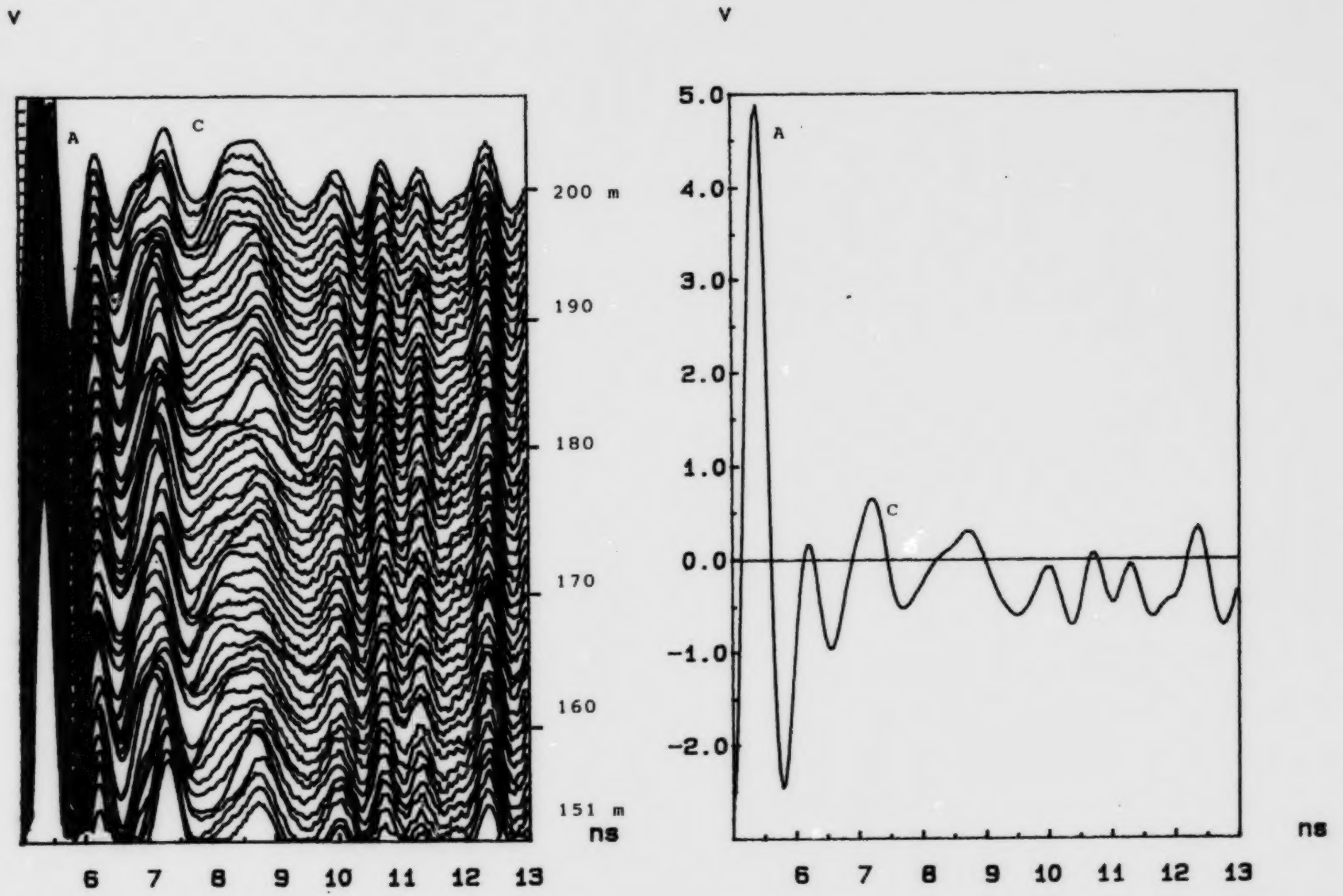
Fig 58: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (51 - 100 m).



Hwy 7, Line 2, 101-150m

average waveform

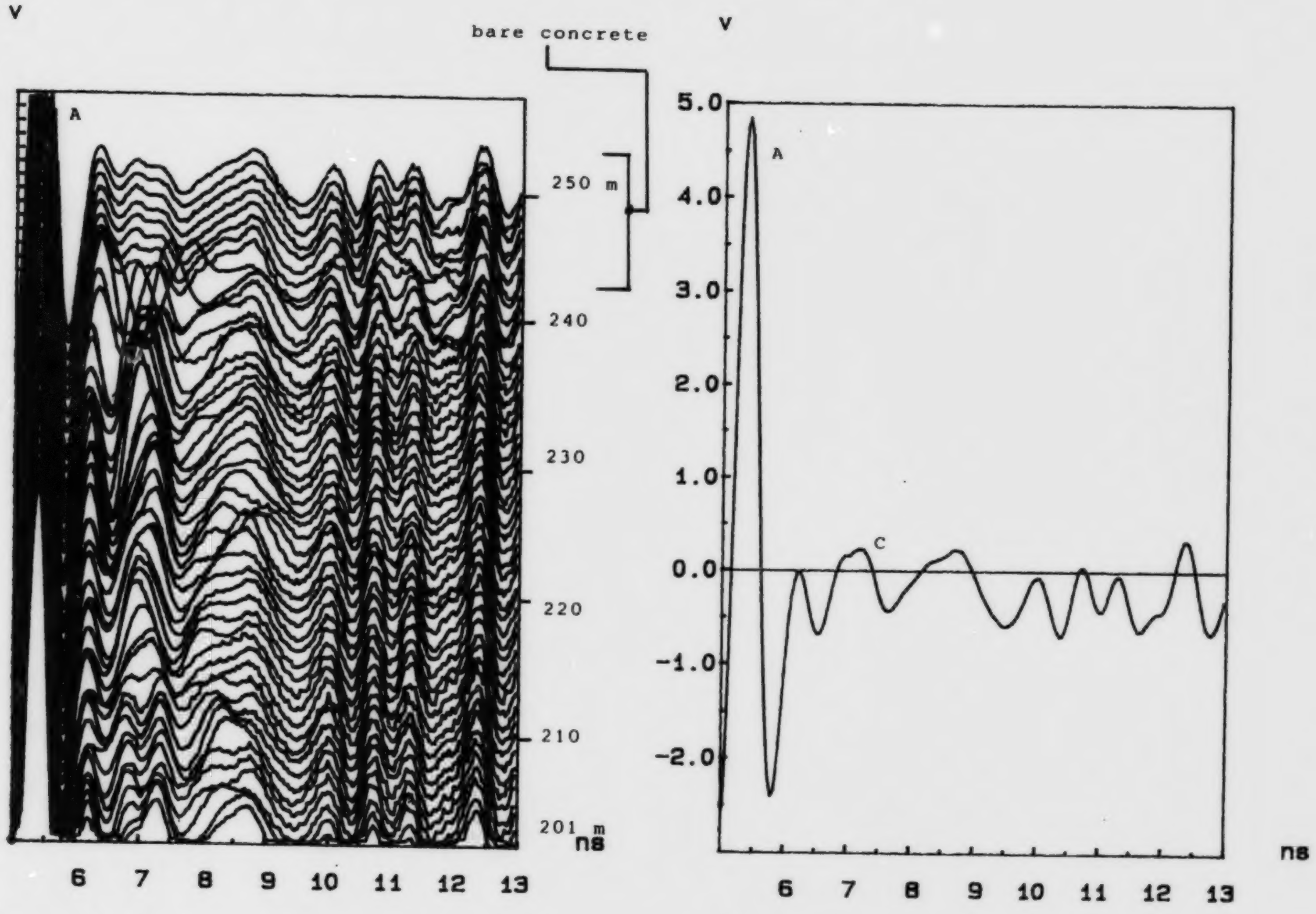
Fig 59: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (101 - 150 m).



Hwy 7. Line 2, 151-200m

average waveform

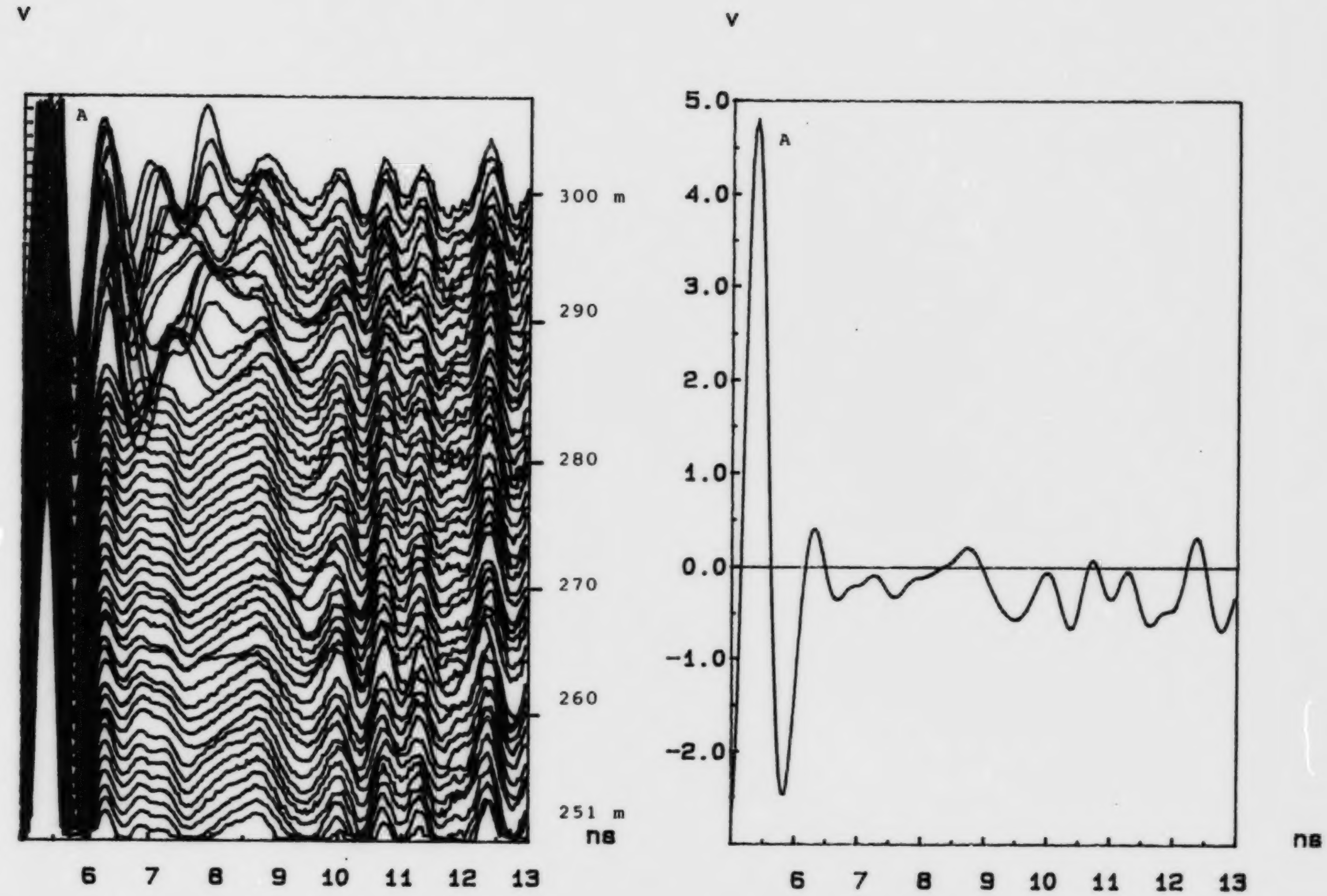
Fig 60: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (151 - 200 m).



Hwy 7. Line 2, 201-250m

average waveform

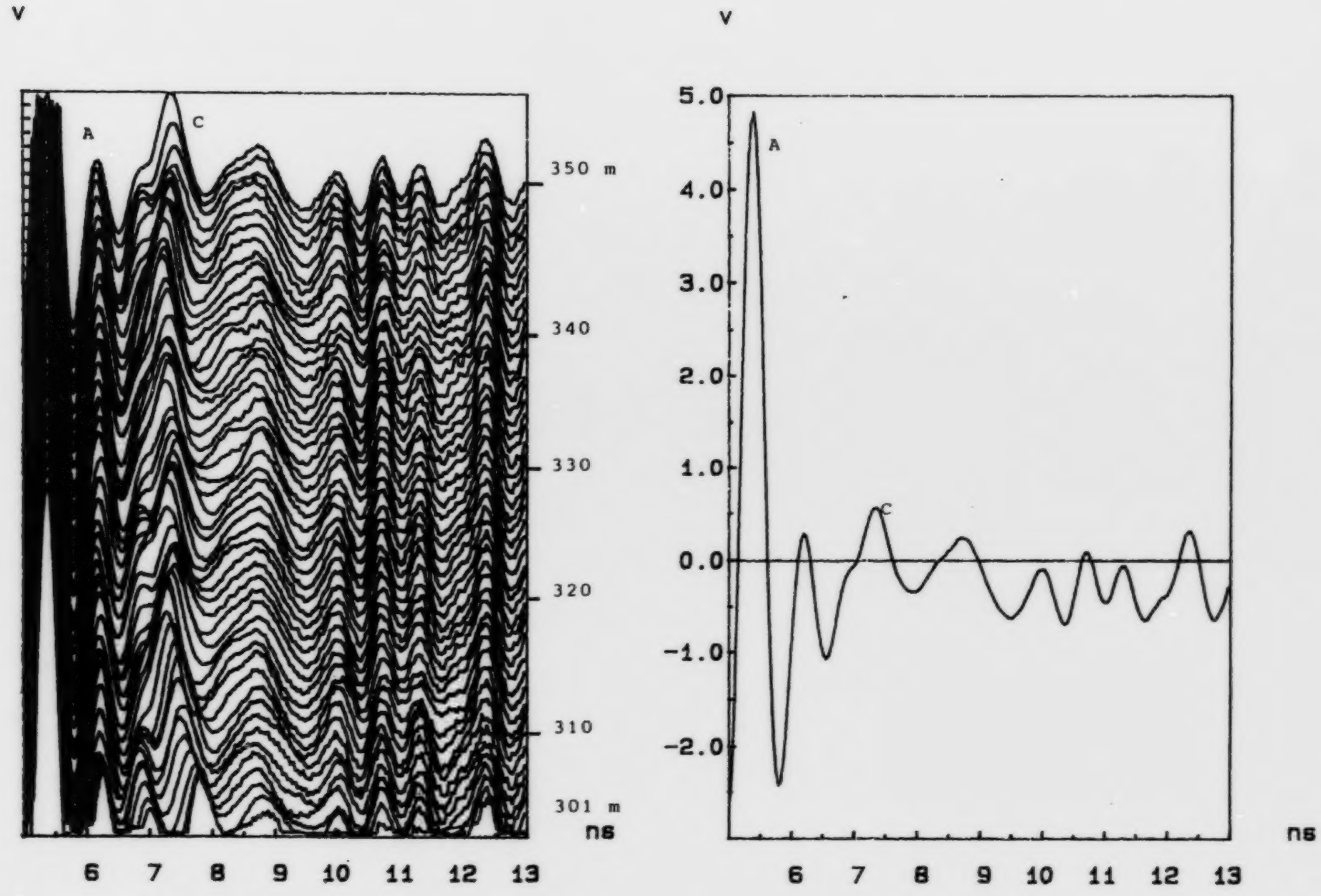
Fig 61: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (201 - 250 m).



Hwy 7. Line 2. 251-300m

average waveform

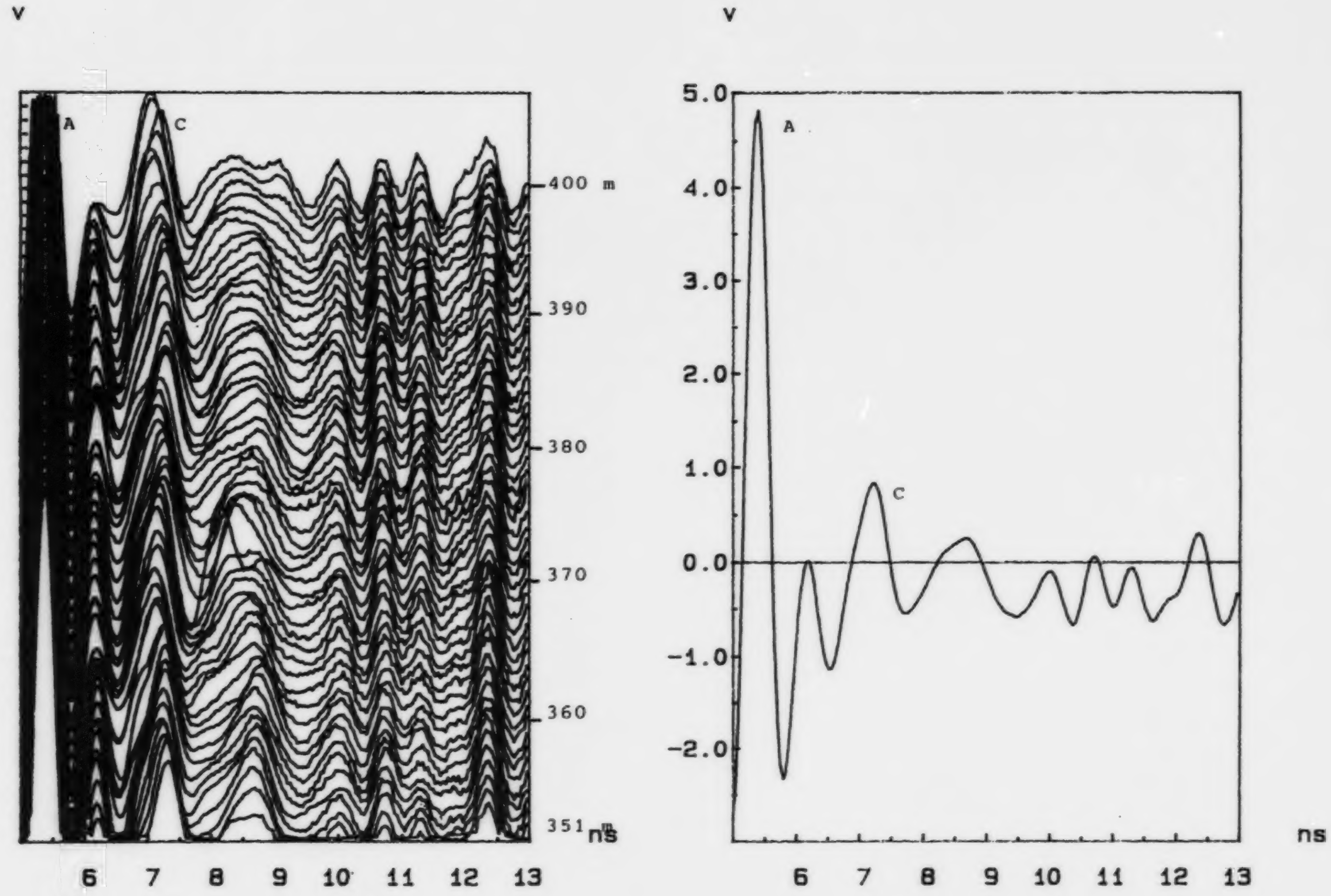
Fig 62: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (251 - 300 m).



Hwy 7, Line 2, 301-350m

average waveform

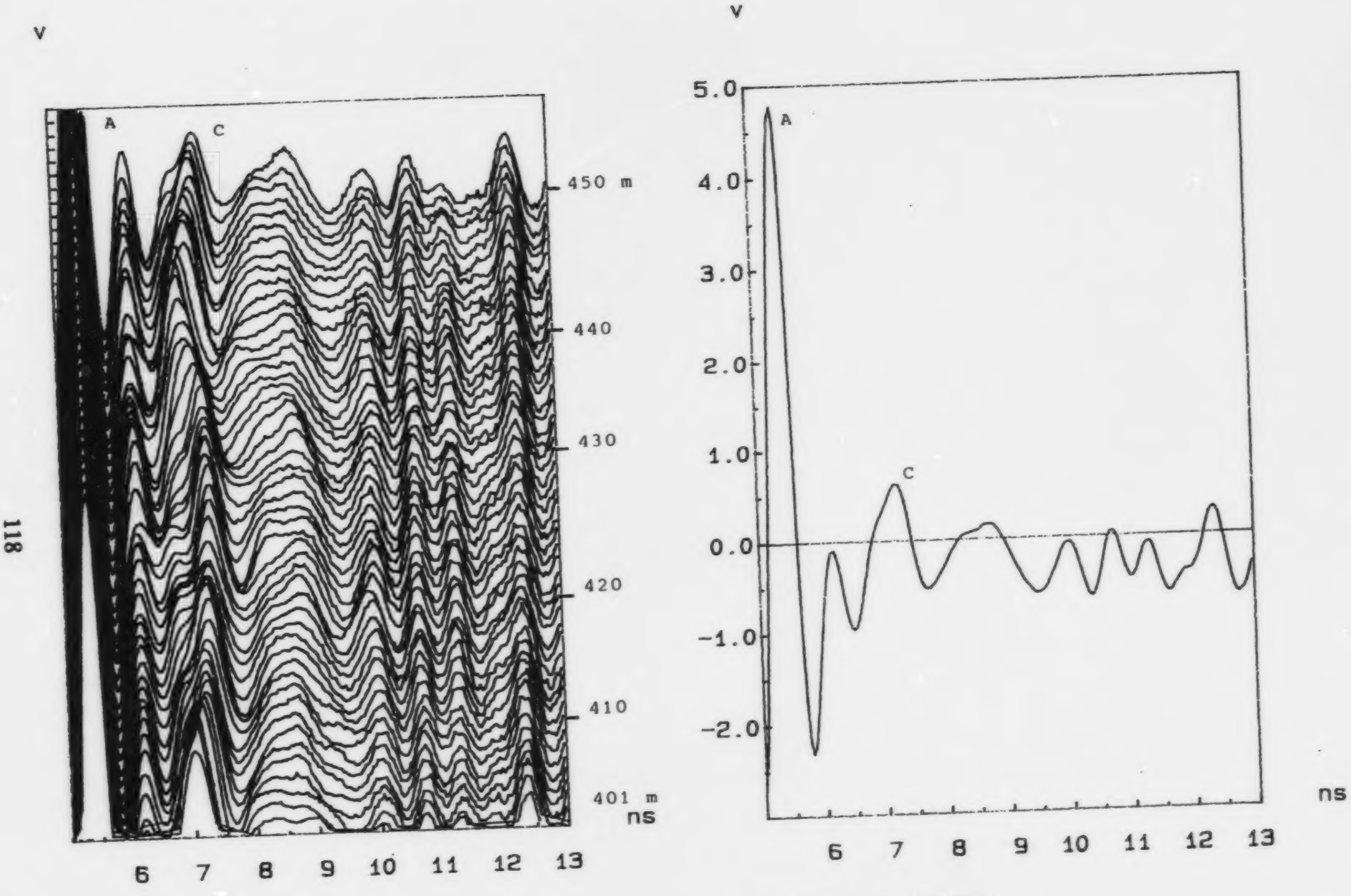
Fig 63: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (301 - 350 m).



Hwy 7, Line 2, 351-400m

average waveform

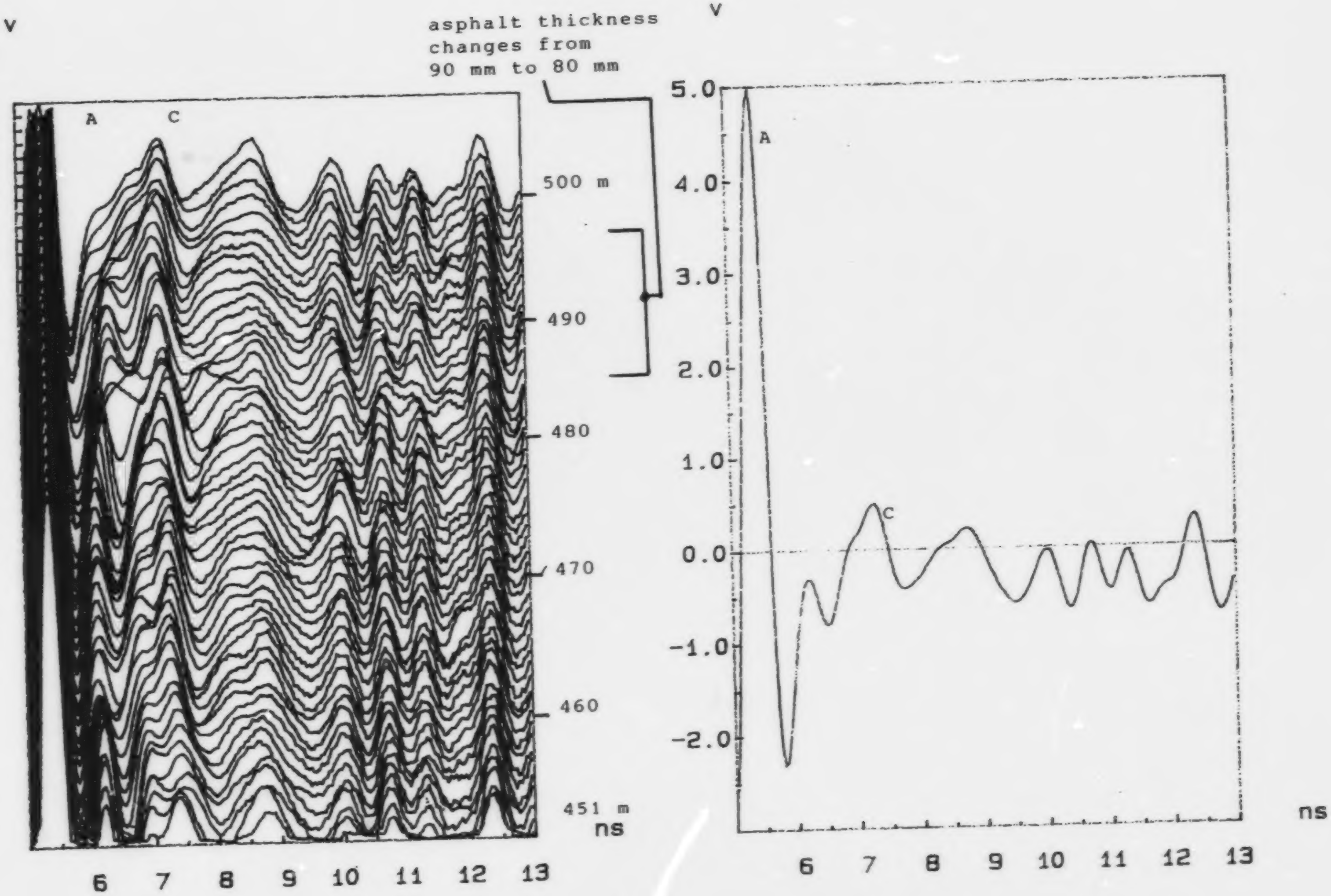
Fig 64: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (351 - 400 m).



Hwy 7, Line 2, 401-450m

average waveform

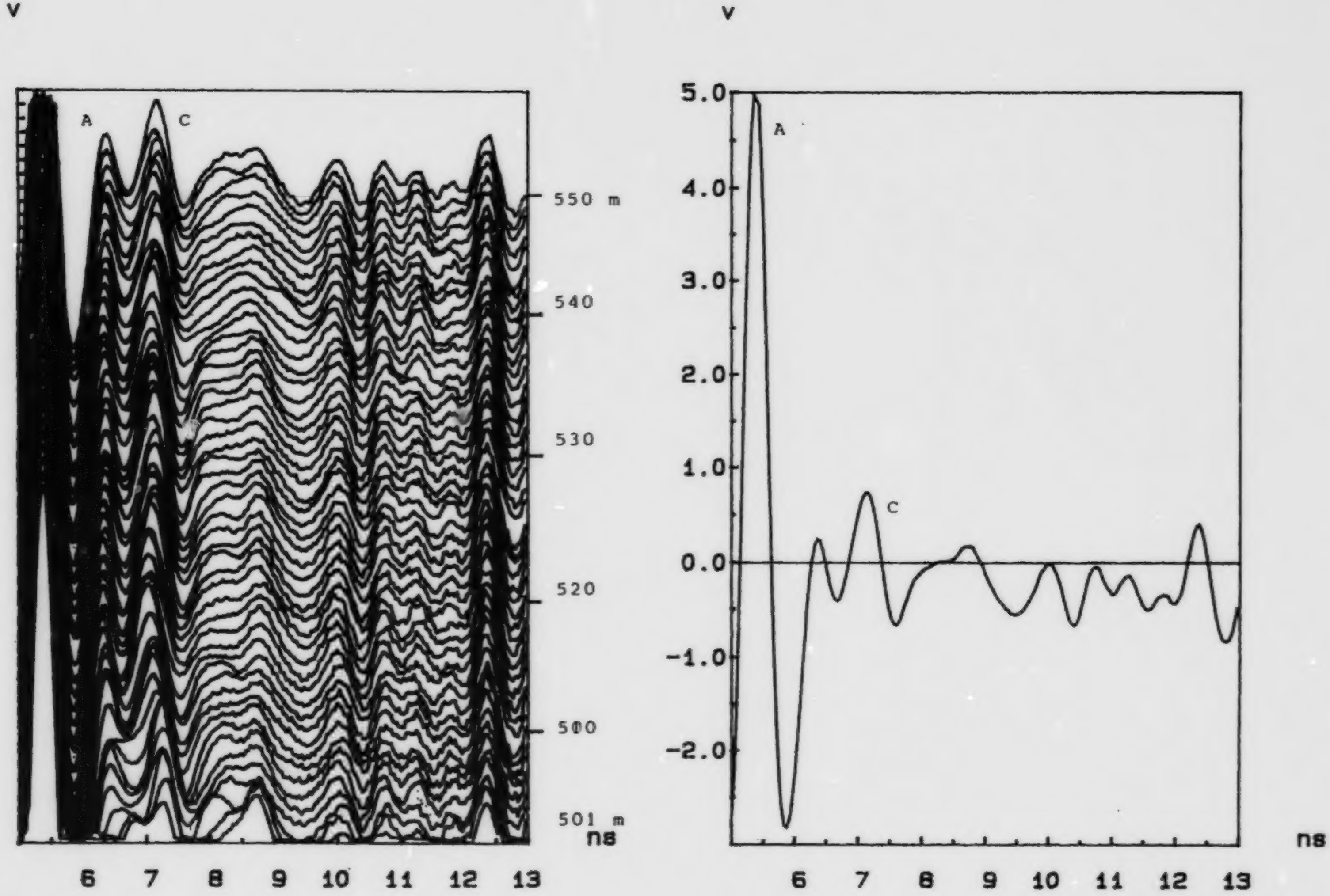
Fig 65: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (401 - 450 m).



Hwy 7, Line 2, 451-500m

average waveform

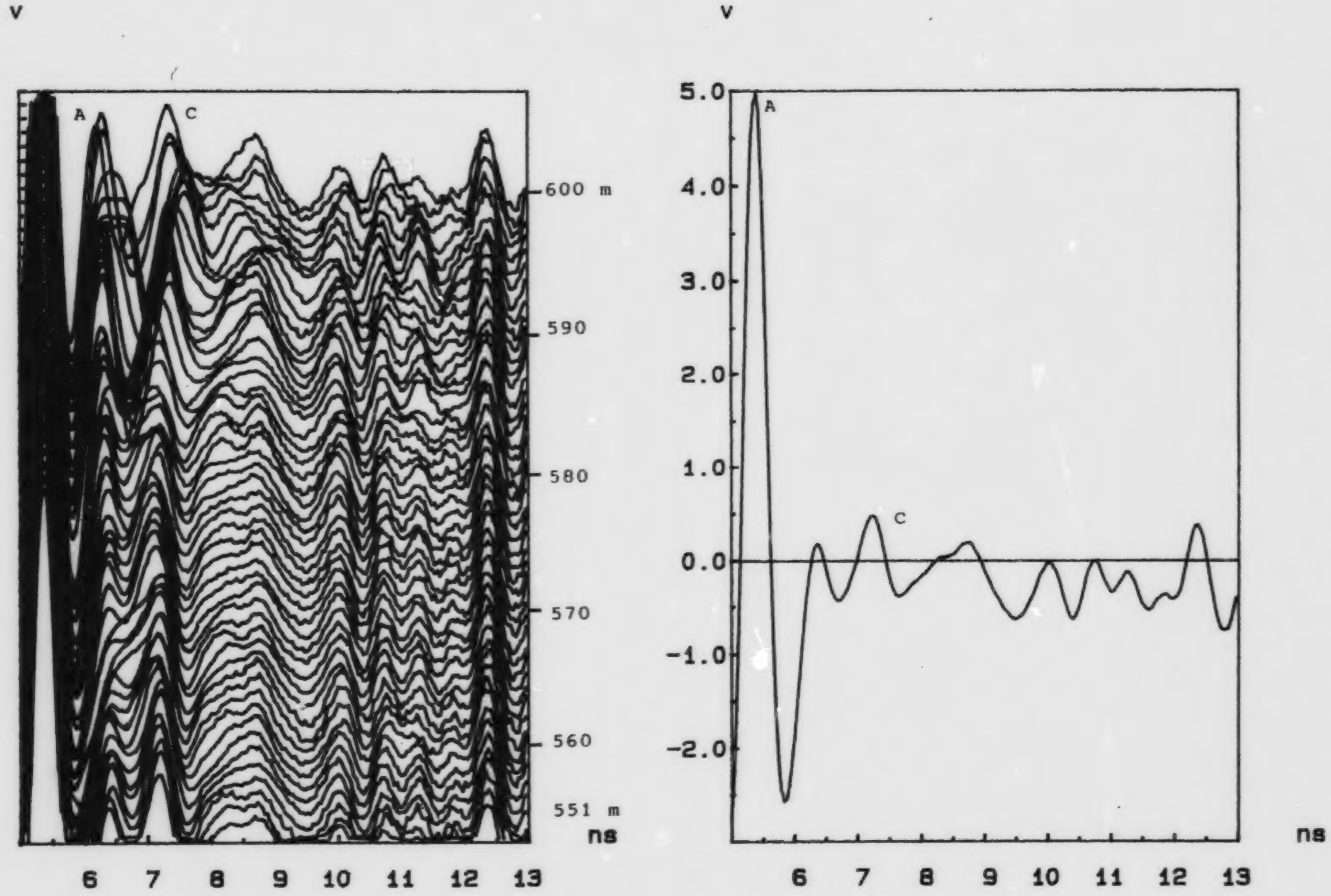
Fig 66: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (451 - 500 m).



Hwy 7. Line 2, 501-550m

average waveform

Fig 67: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (501 - 550 m).



Hwy 7, Line 2, 551-600m

average waveform

Fig 68: Hwy. 7/Dufferin (1990) - STC waveforms from Line 2 (551 - 600 m).

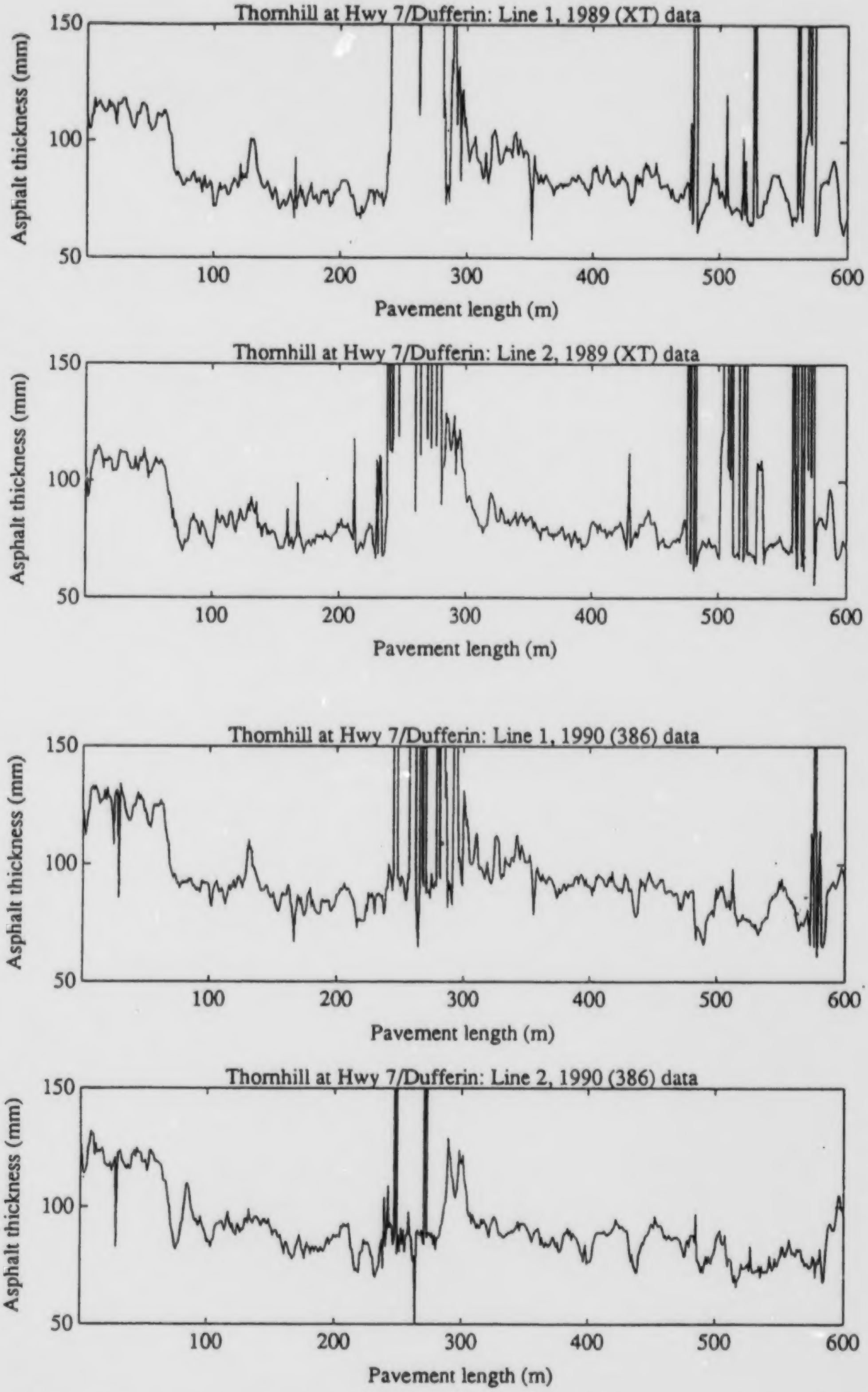


Fig 69: Hwy. 7/Dufferin - Plots of asphalt thickness from 1989/1990 surveys.

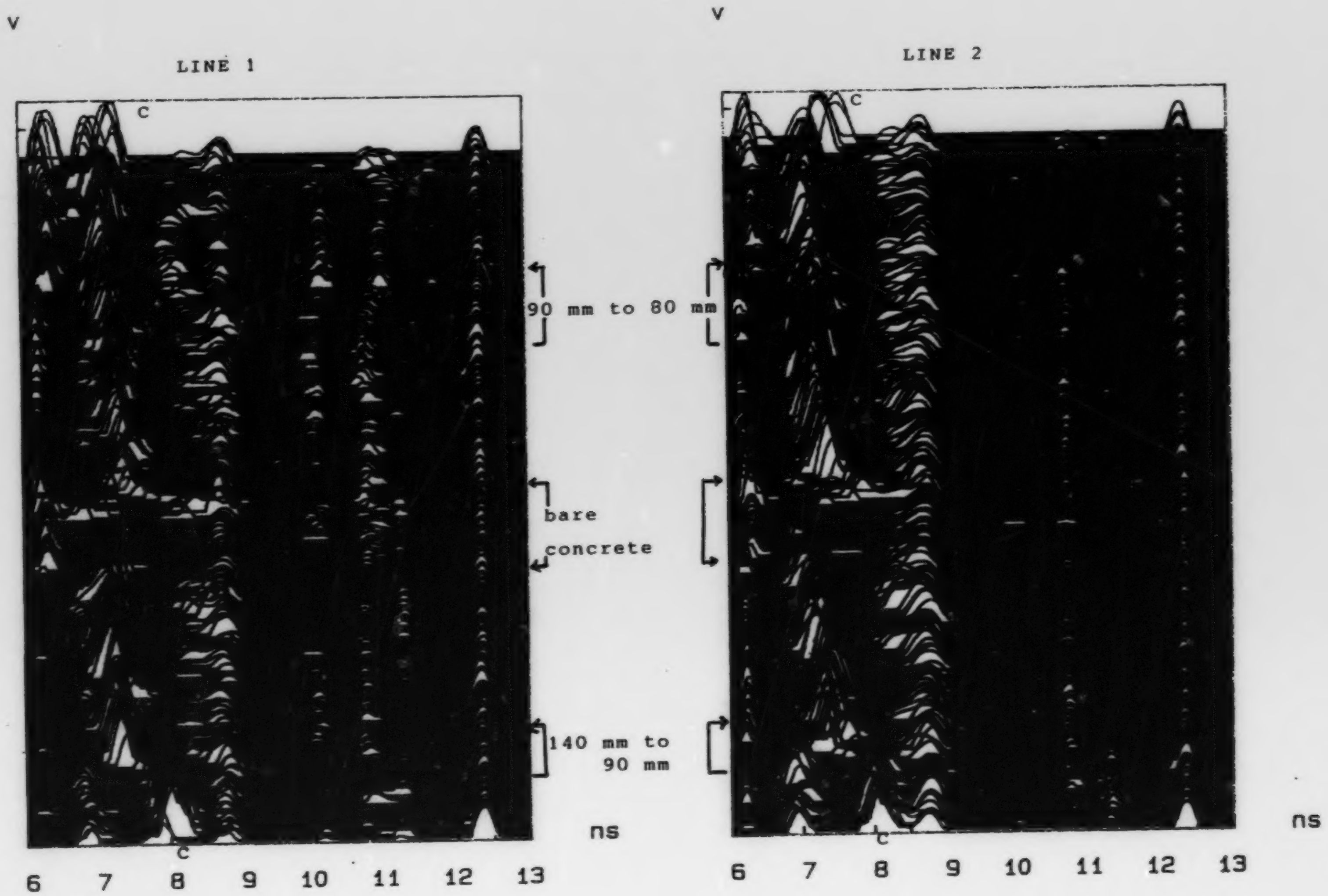


Fig 70: Hwy. 7/Dufferin (1990) - Profile plots from Lines 1 and 2 using STC and 0.0 V threshold.

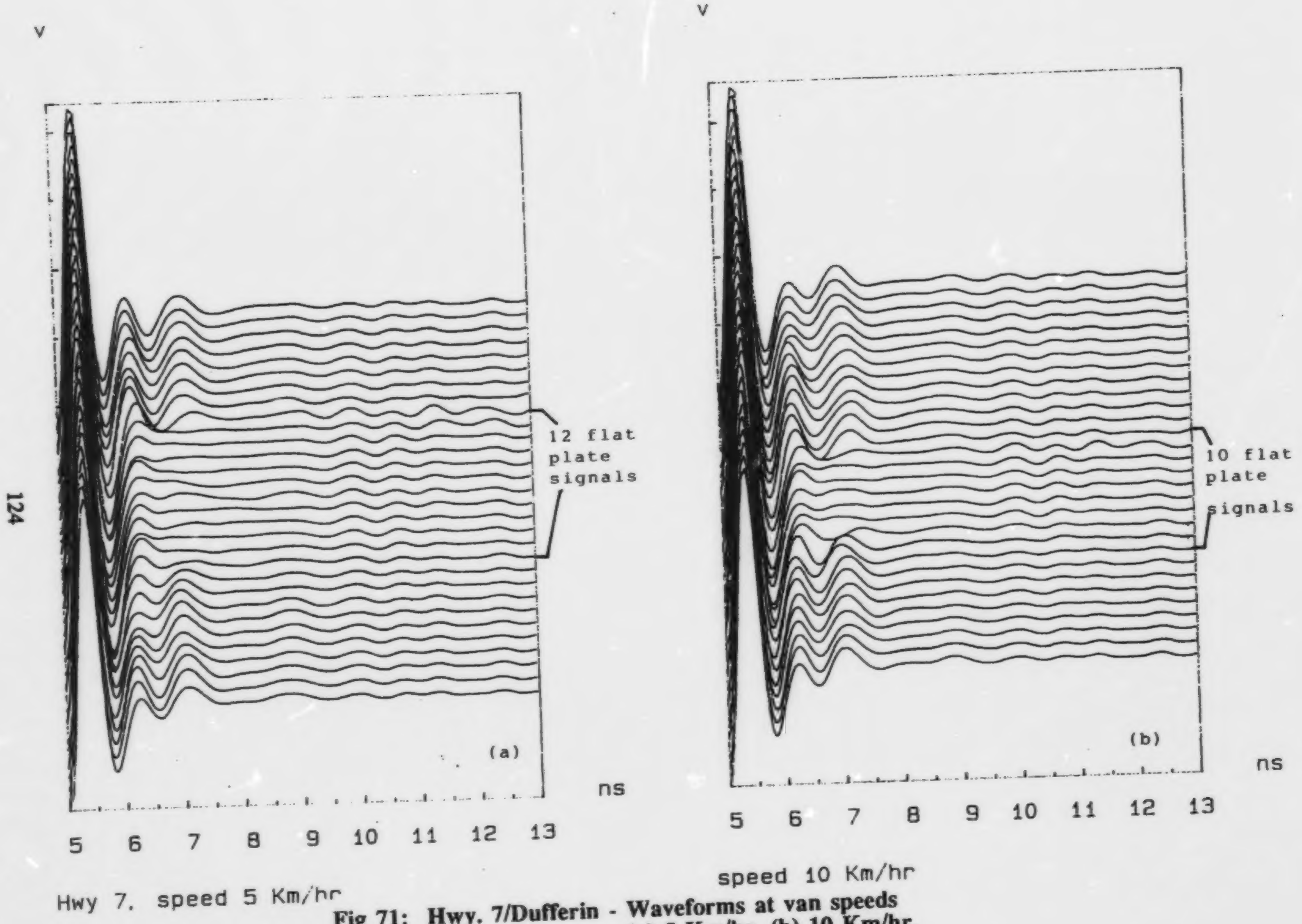
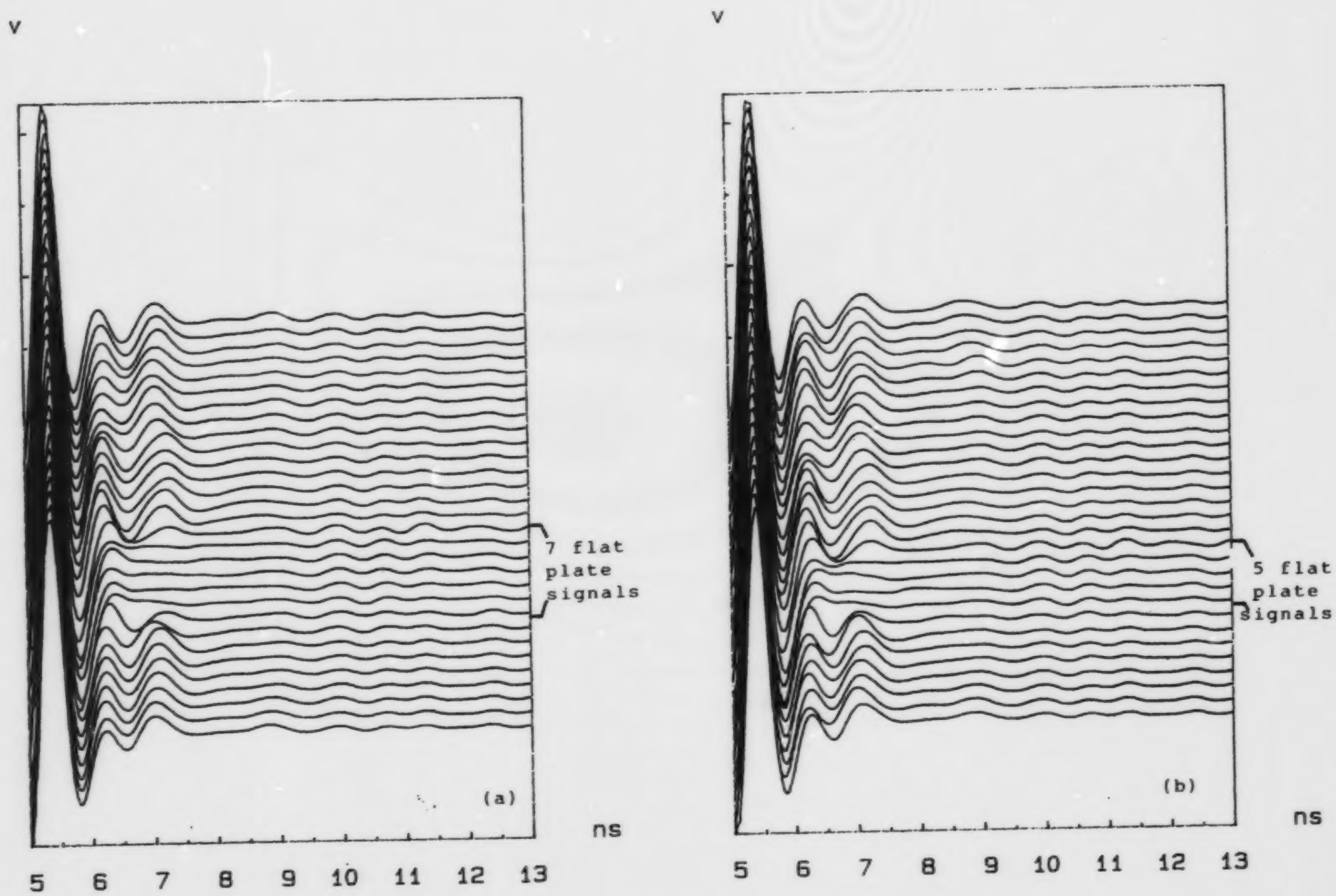


Fig 71: Hwy. 7/Dufferin - Waveforms at van speeds
(a) 5 Km/hr, (b) 10 Km/hr.



Hwy 7. speed 15 Km/hr

speed 20 Km/hr

Fig 72: Hwy. 7/Dufferin - Waveforms at van speeds
(a) 15 Km/hr, (b) 20 Km/hr.

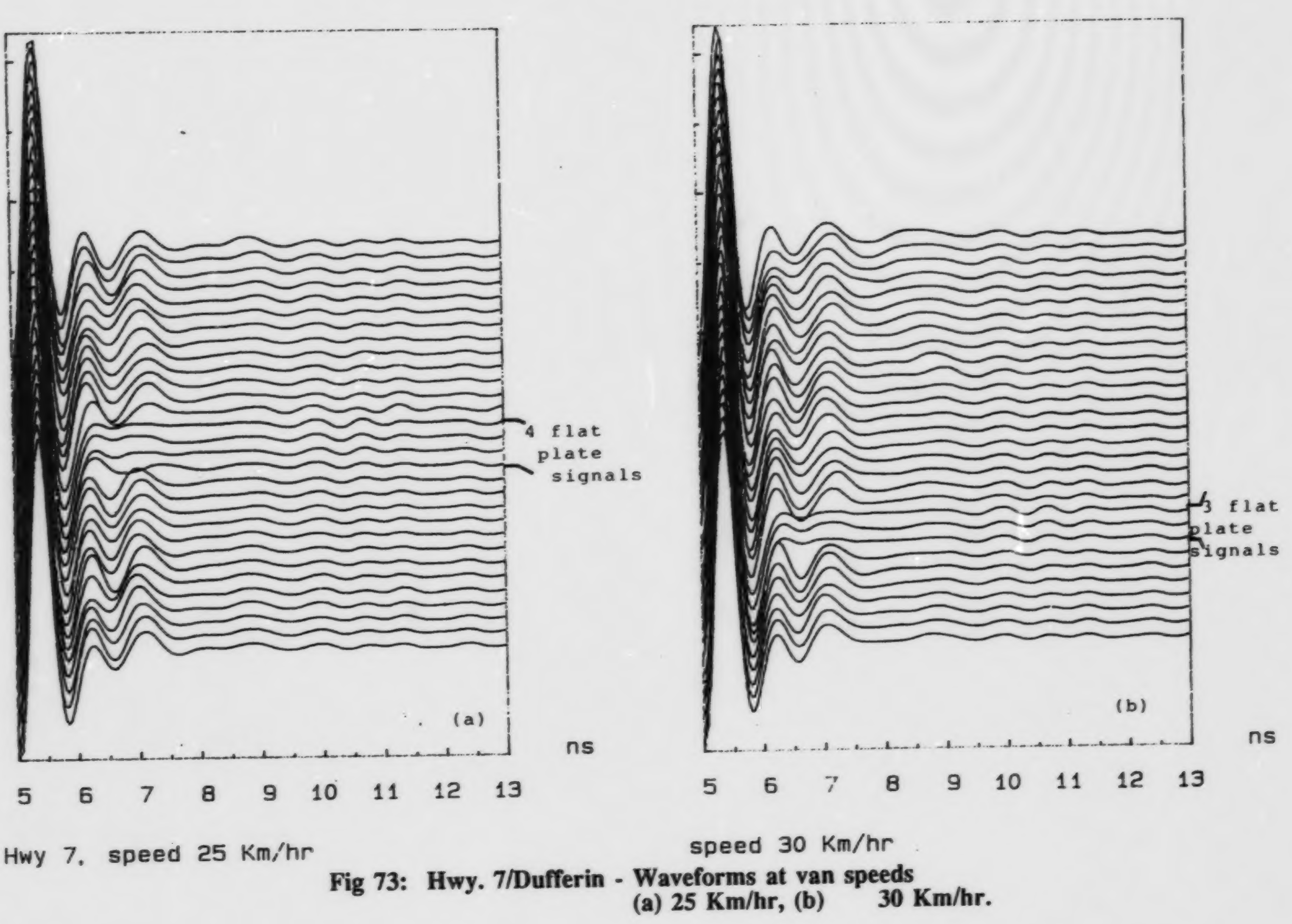


Fig 73: Hwy. 7/Dufferin - Waveforms at van speeds
(a) 25 Km/hr, (b) 30 Km/hr.

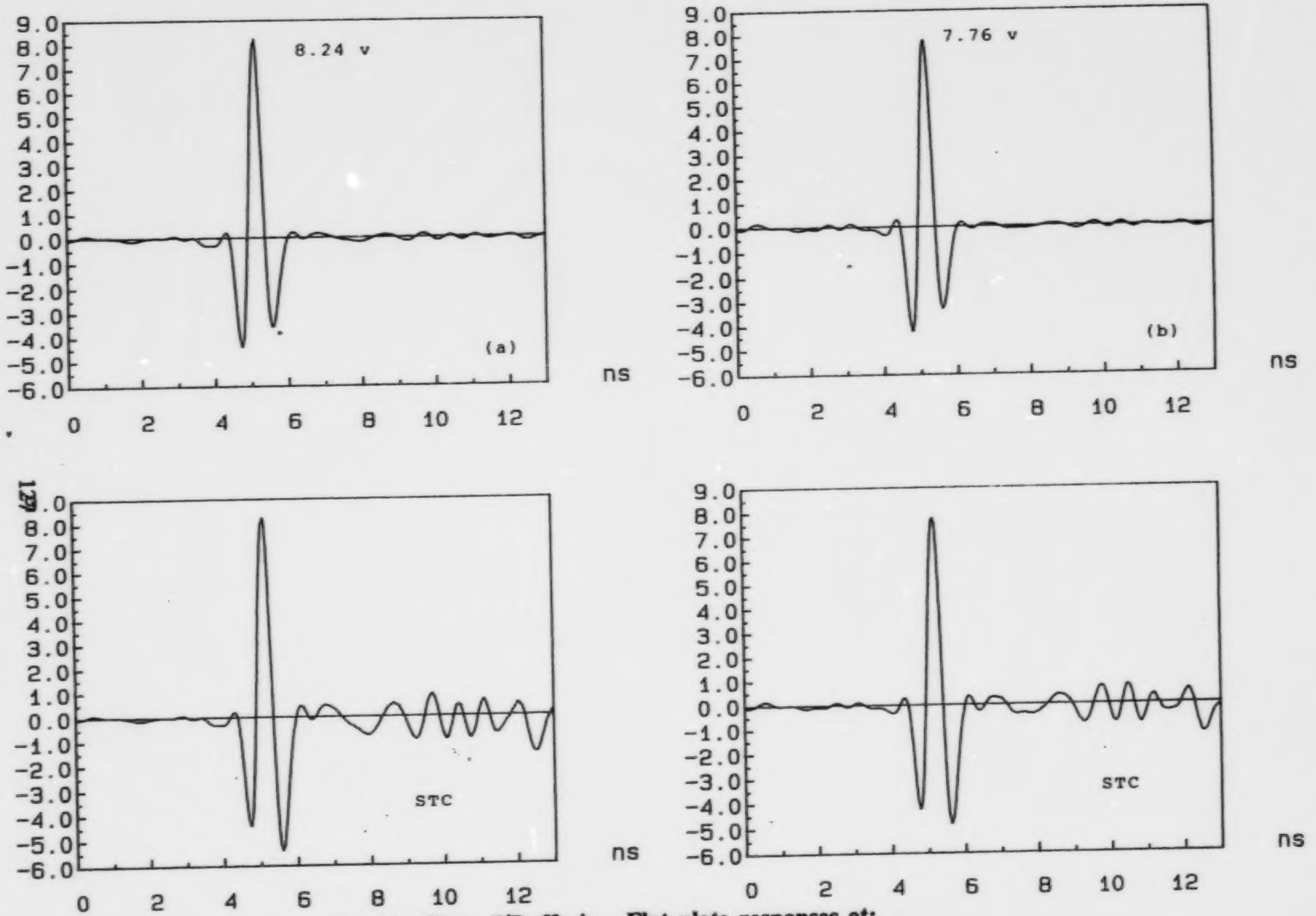


Fig 74: Hwy. 7/Dufferin - Flat plate responses at:
(a) 5 Km/hr, (b) 10 Km/hr.

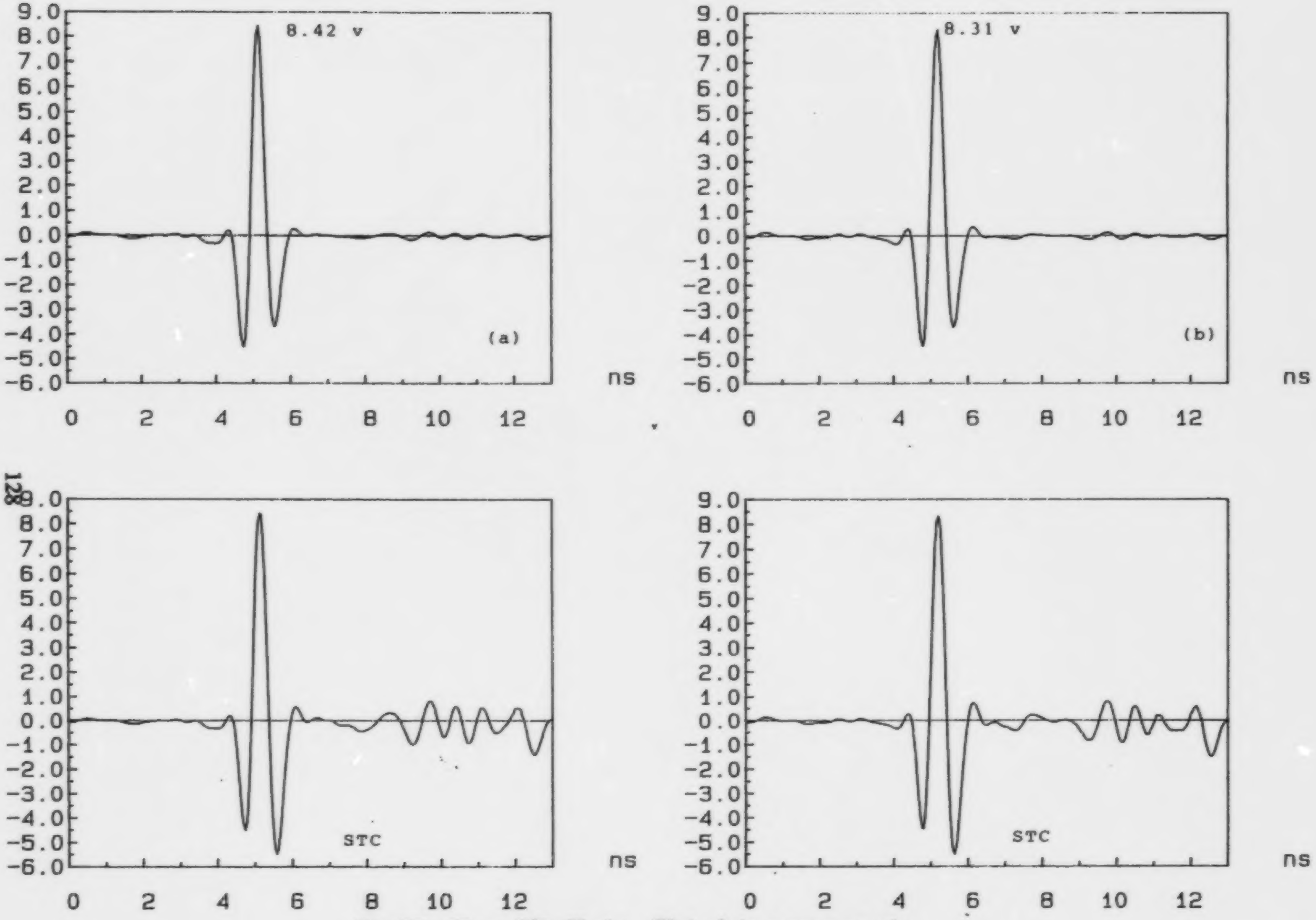


Fig 75: Hwy. 7/Dufferin - Flat plate responses at:
(a) 15 Km/hr, (b) 20 Km/hr.

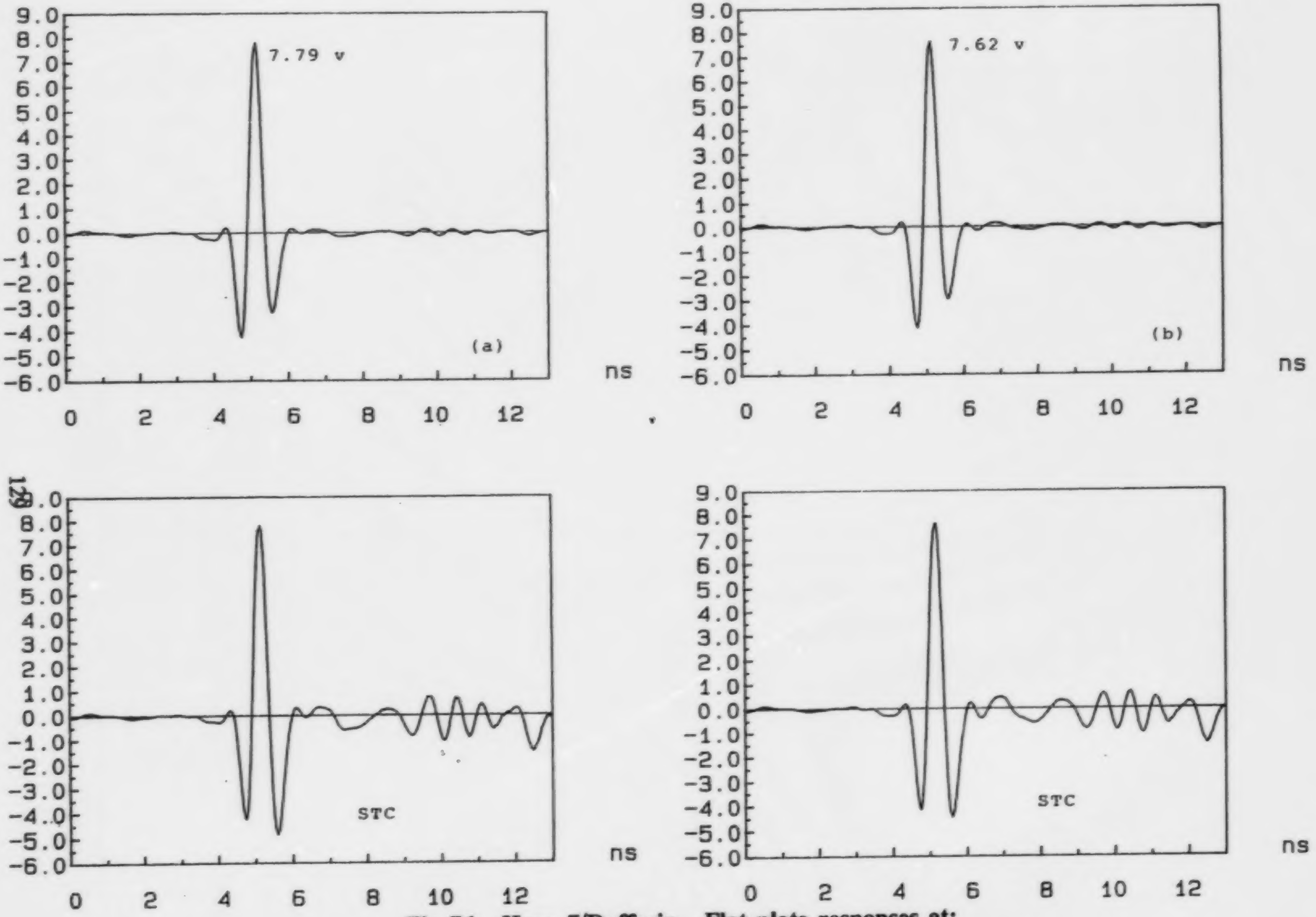
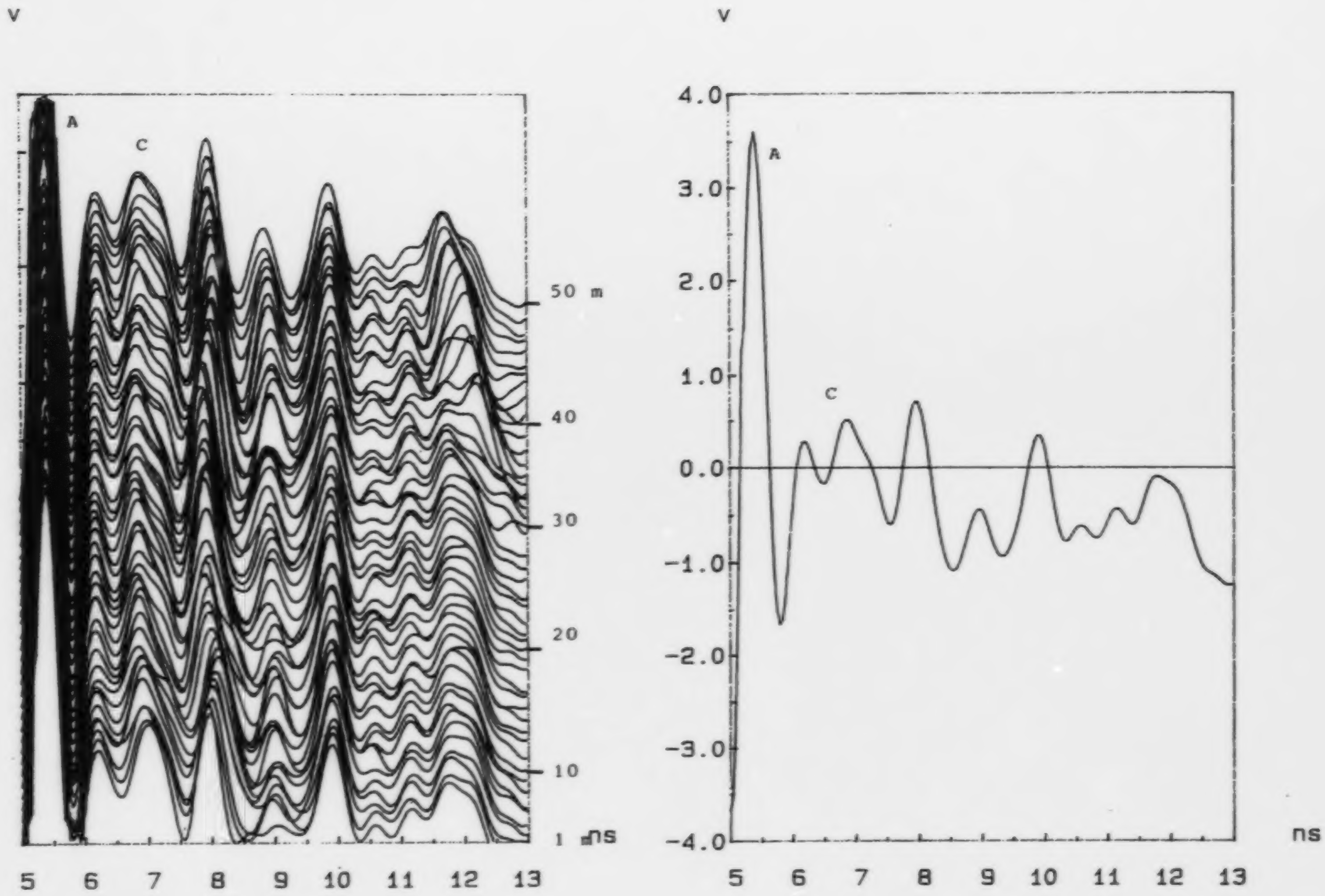


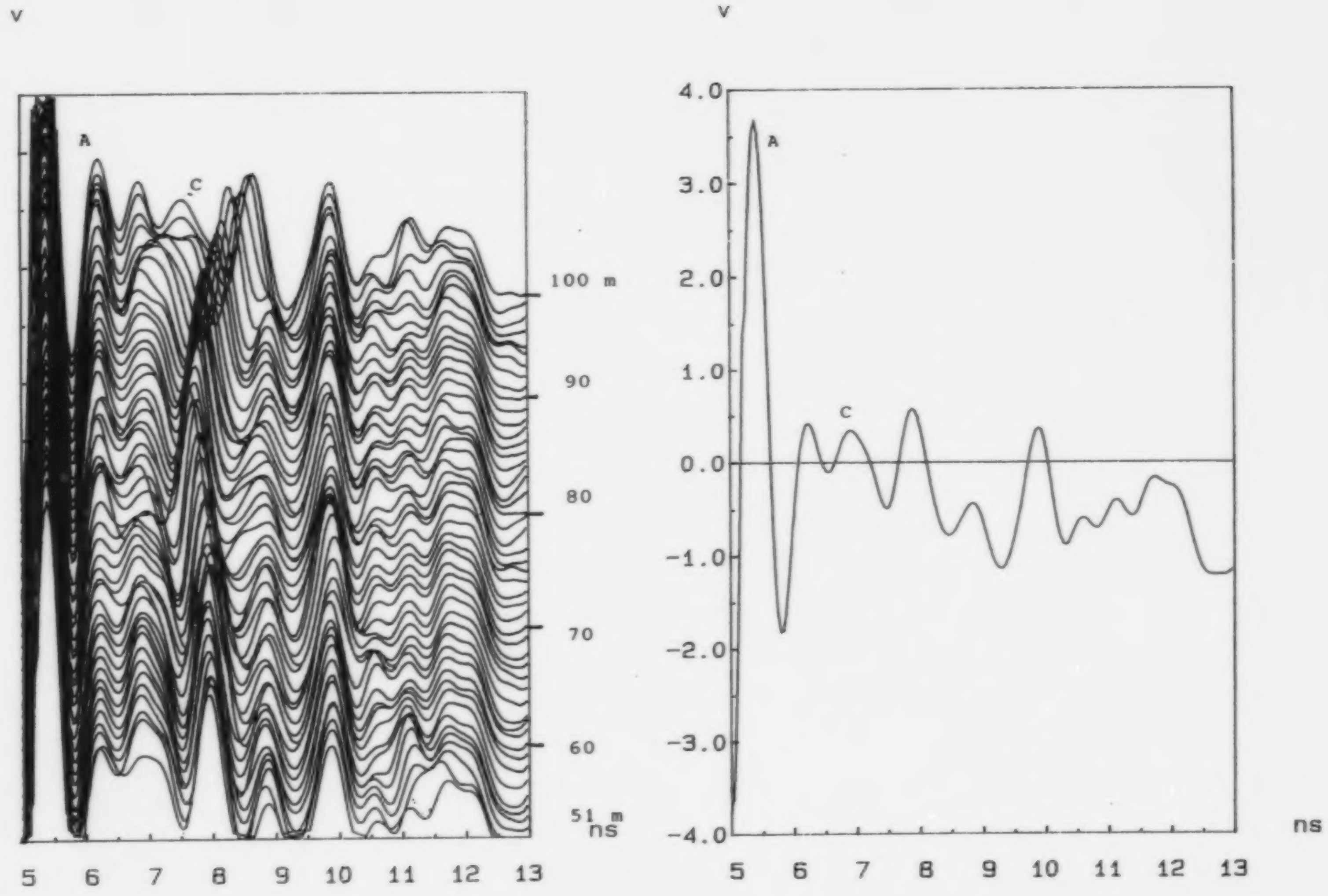
Fig 76: Hwy. 7/Dufferin - Flat plate responses at:
(a) 25 Km/hr, (b) 30 Km/hr.



Hwy 12, east bound, 1-50m

Average Waveform

Fig 77: Hwy. 12/400 - STC waveforms from section (1 - 50 m).



Hwy 12. east bound. 51-100m

Average Waveform

Fig 78: Hwy. 12/400 - STC waveforms from section (51 - 100 m).

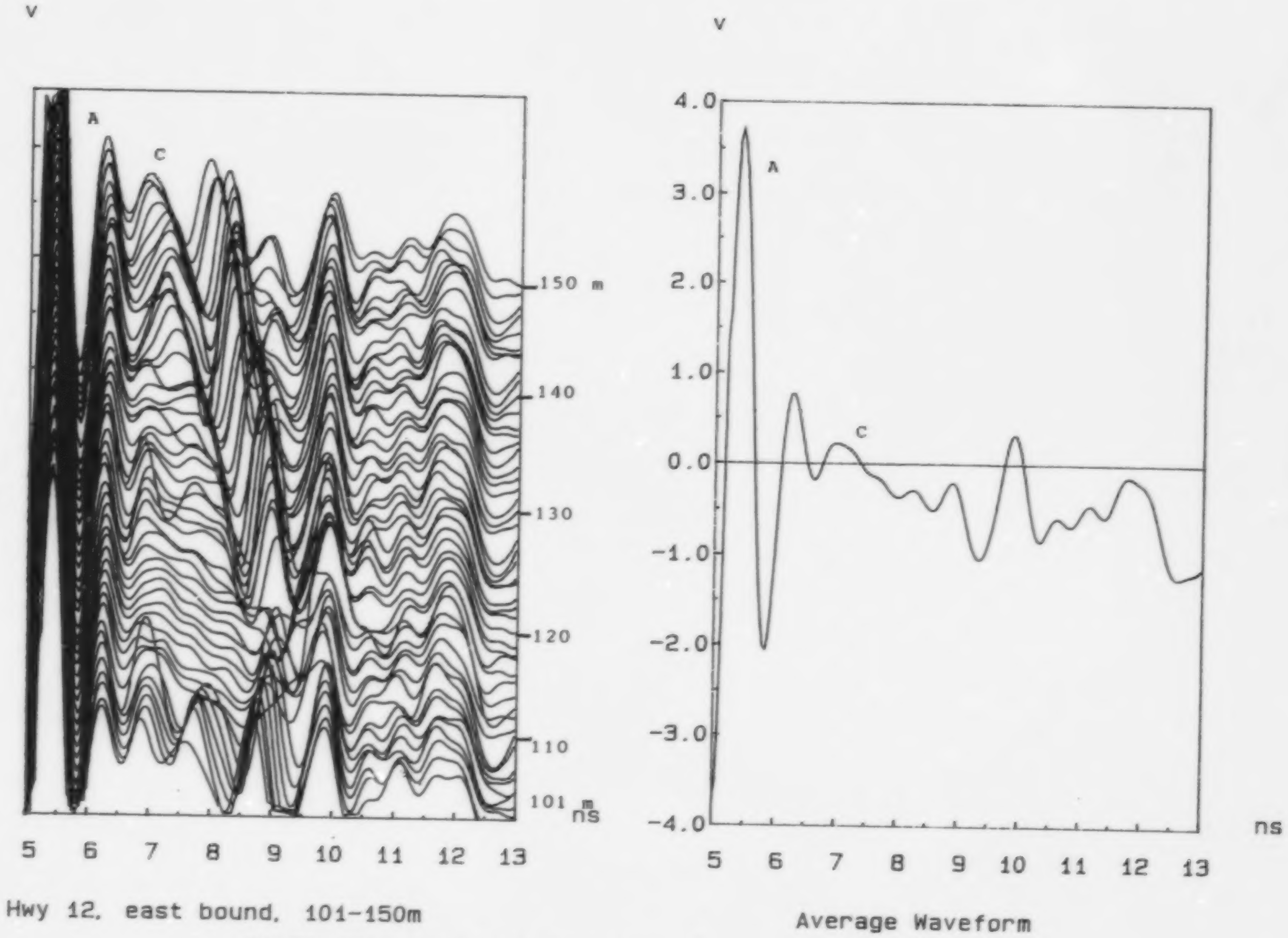
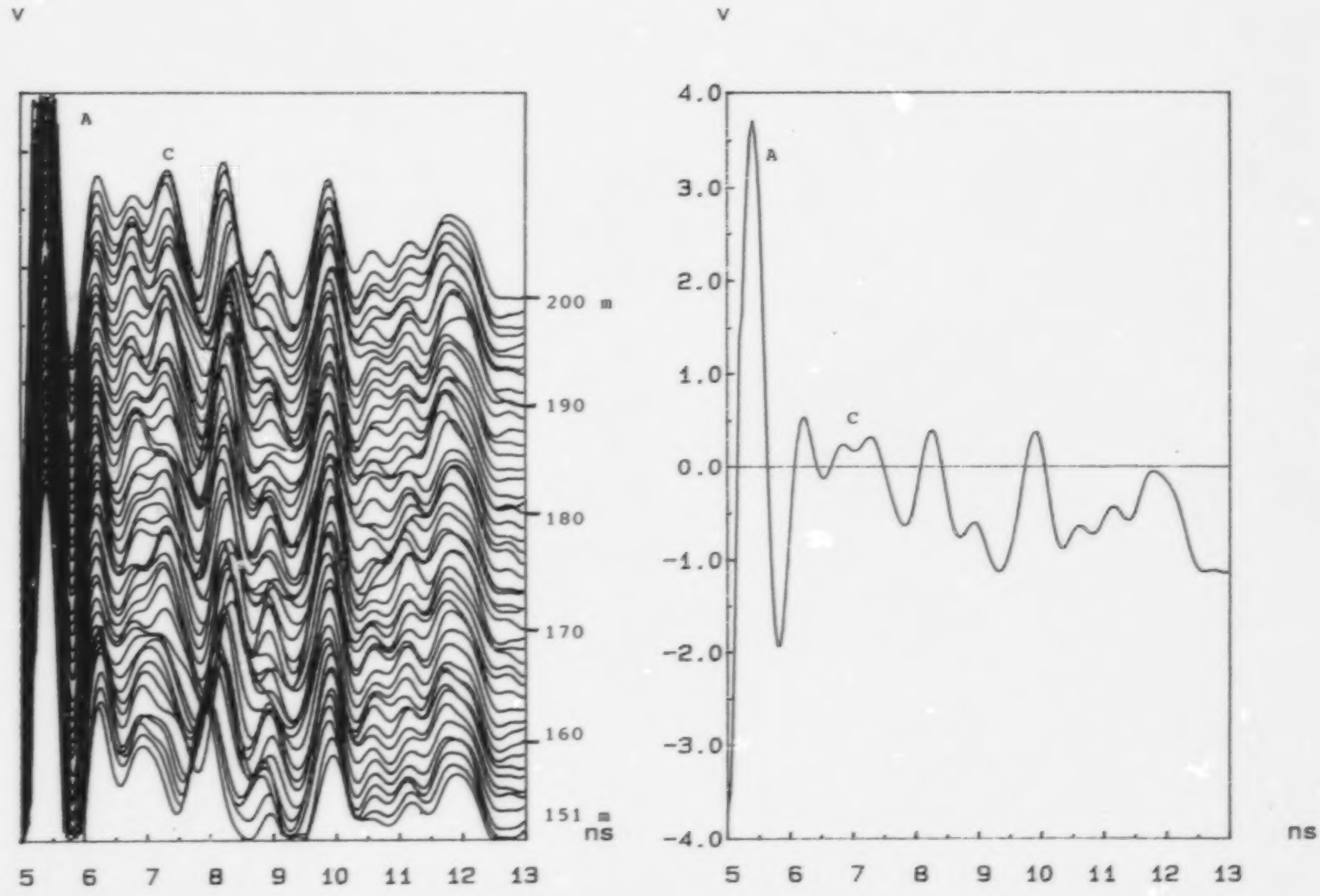


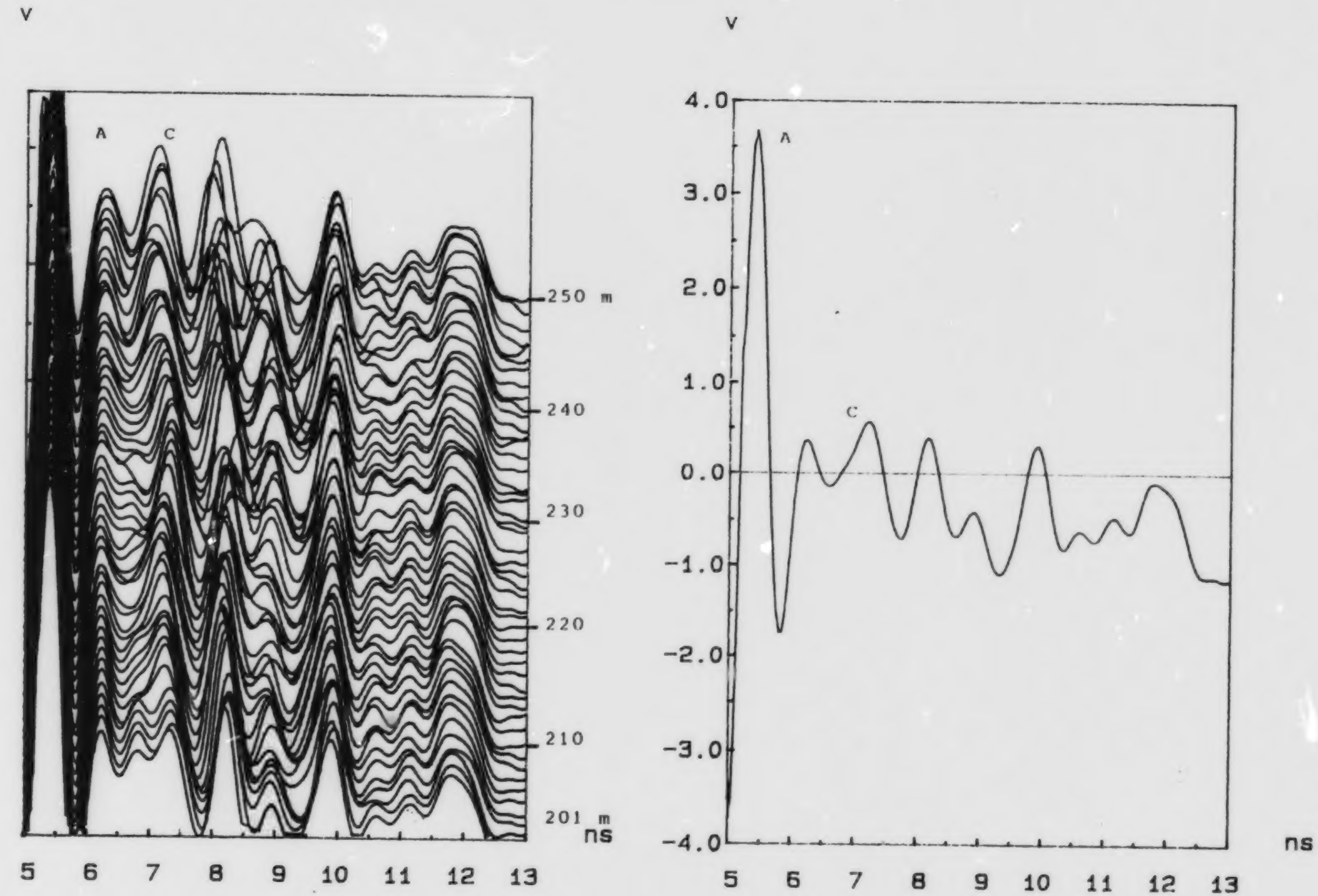
Fig 79: Hwy. 12/400 - STC waveforms from section (101 - 150 m).



Hwy 12, east bound, 151-200m

Average Waveform

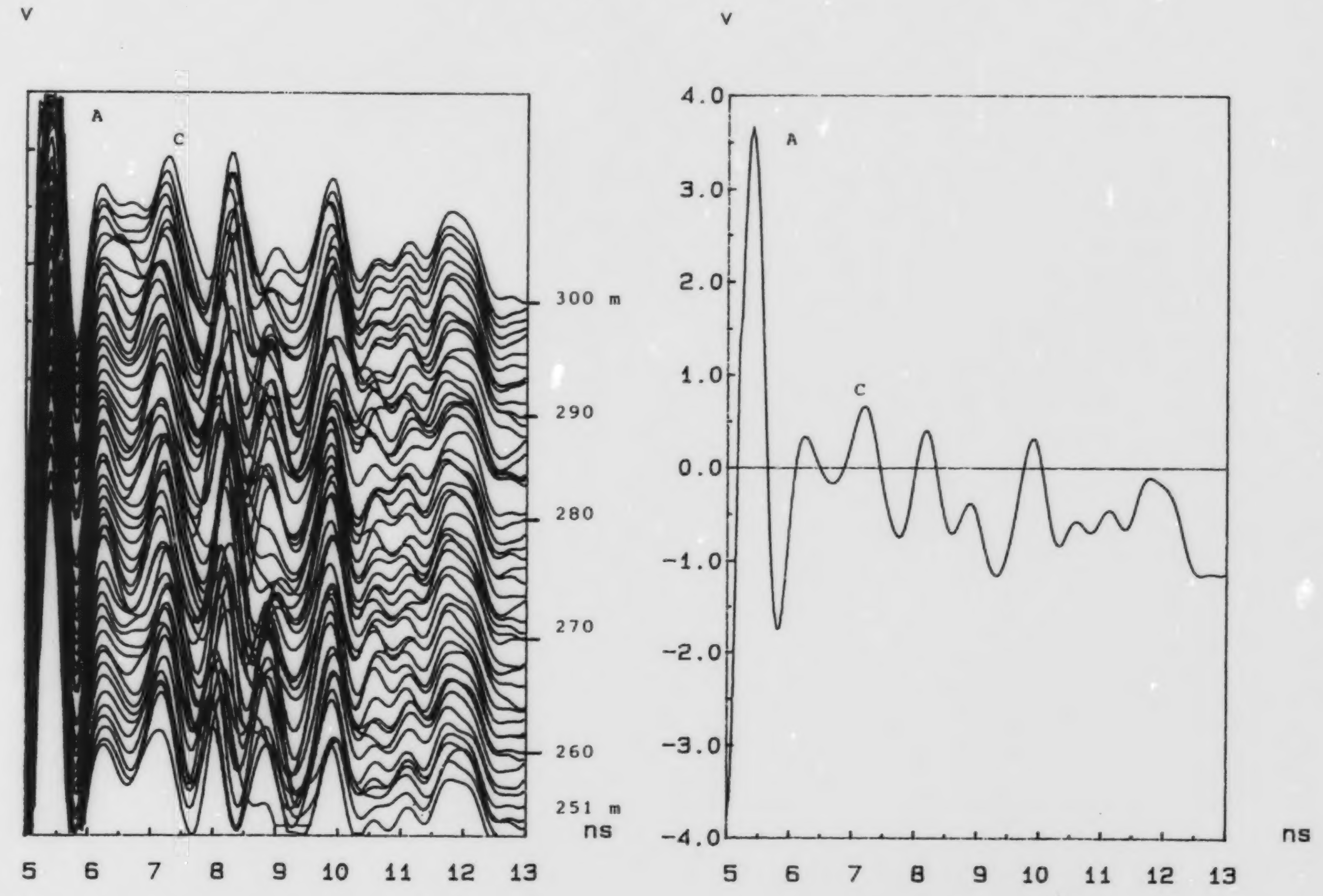
Fig 80: Hwy. 12/400 - STC waveforms from section (151 - 200 m).



Hwy 12, east bound, 201-250m

Average Waveform

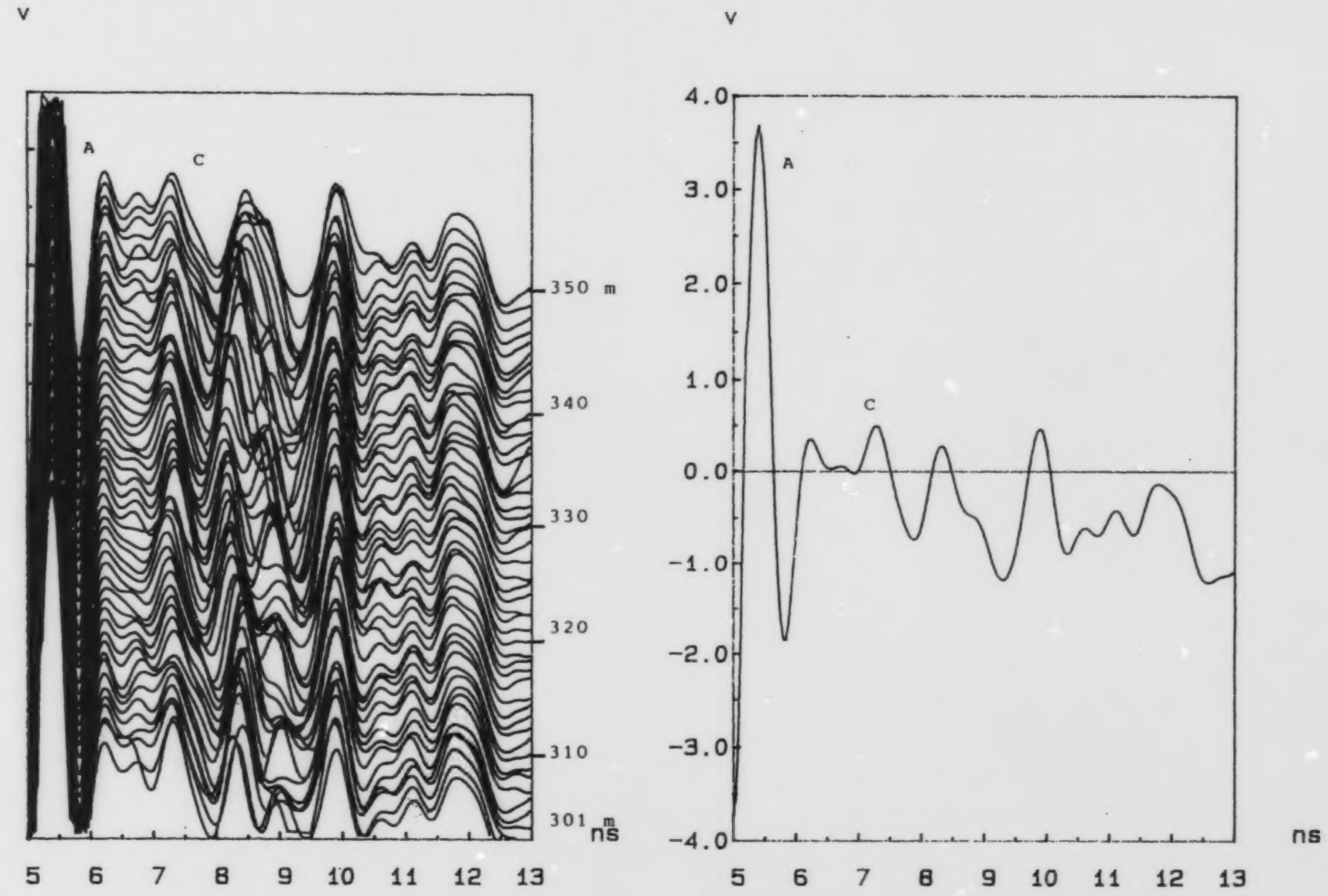
Fig 81: Hwy. 12/400 - STC waveforms from section (201 - 250 m).



Hwy 12, east bound, 251-300m

Average Waveform

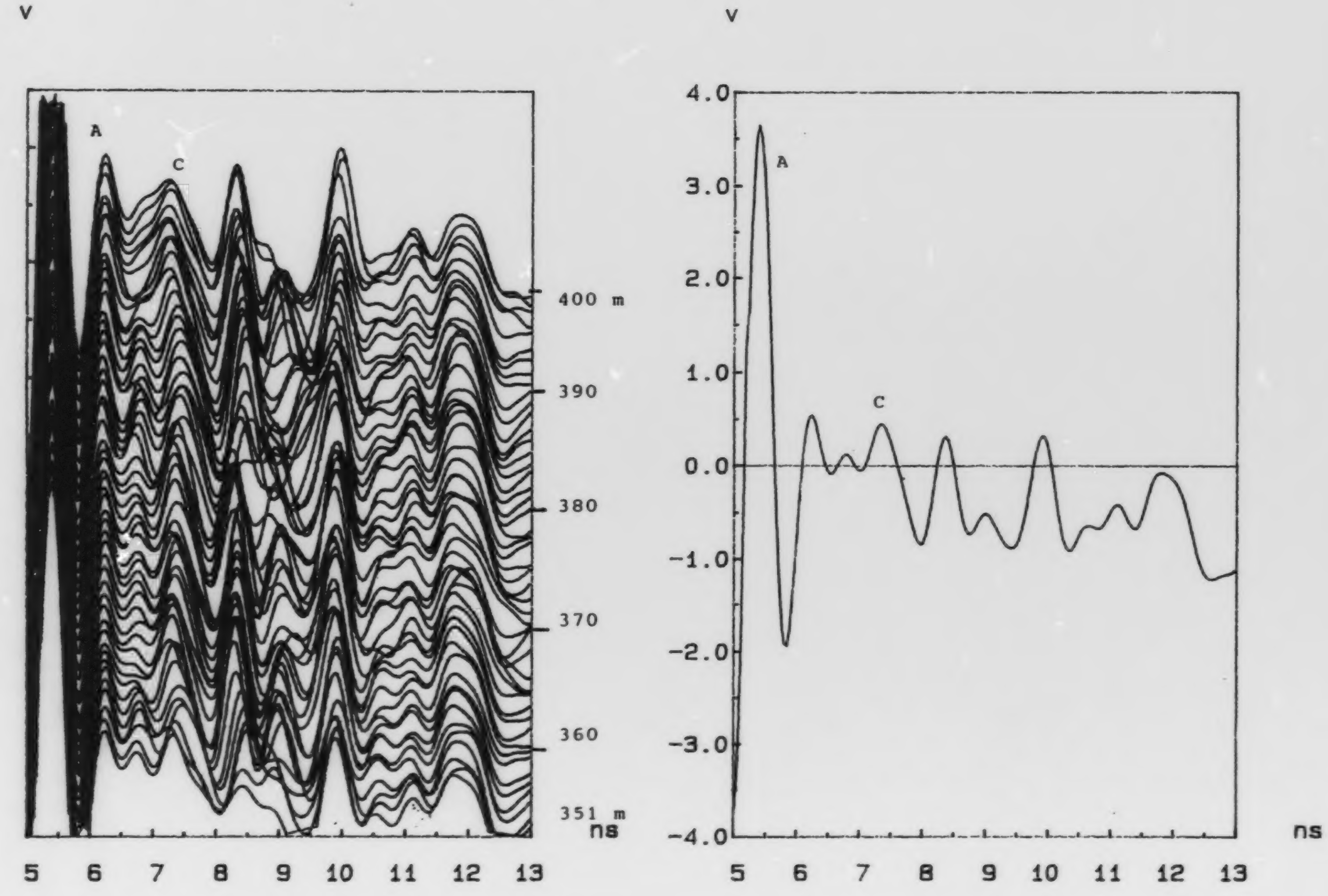
Fig 82: Hwy. 12/400 - STC waveforms from section (251 - 300 m).



Hwy 12, east bound, 301–350m

Average Waveform

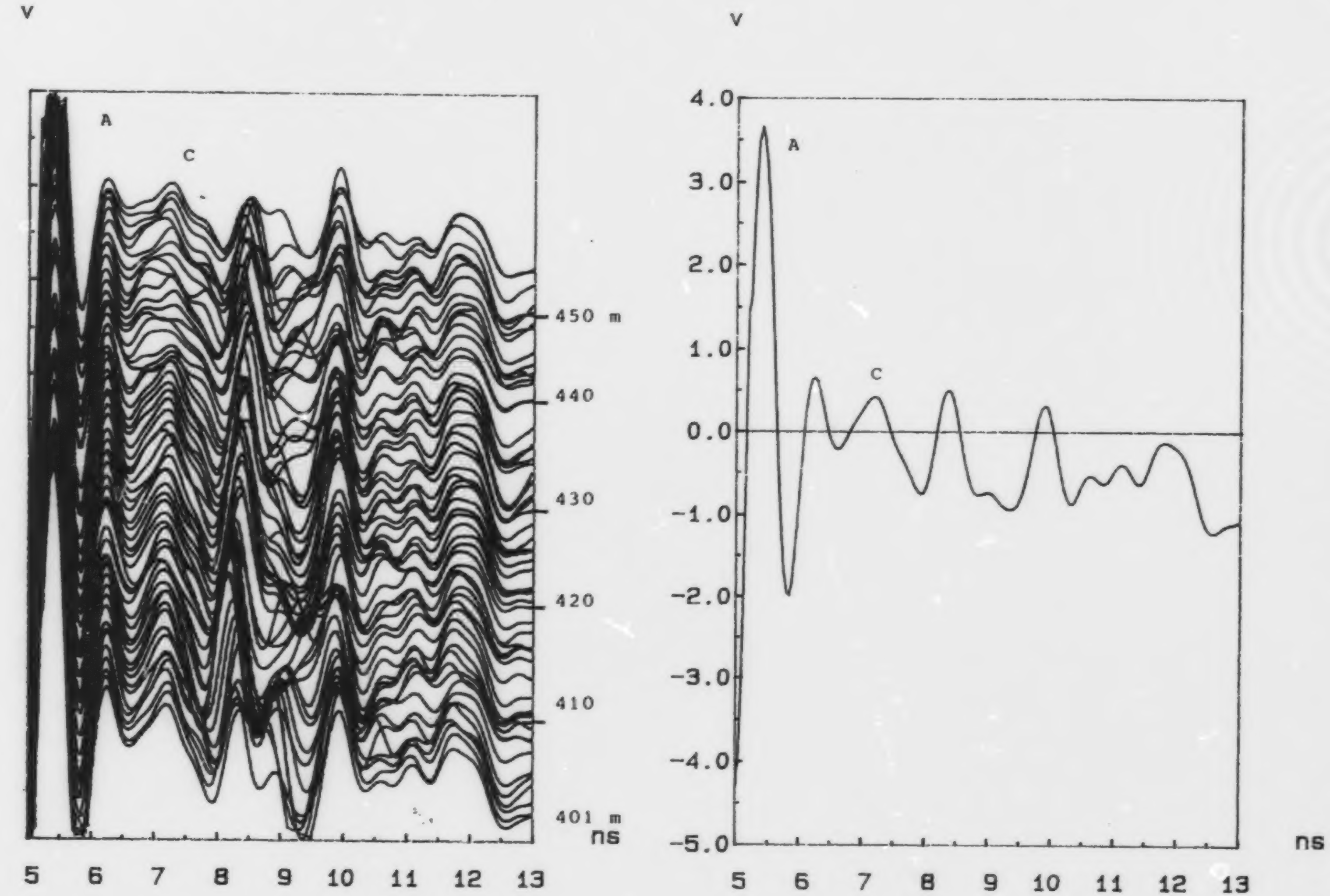
Fig 83: Hwy. 12/400 - STC waveforms from section (301 - 350 m).



Hwy 12, east bound, 351-400m

Average Waveform

Fig 84: Hwy. 12/400 - STC waveforms from section (351 - 400 m).



Hwy 12, east bound, 401-457m

Average Waveform

Fig 85: Hwy. 12/400 - STC waveforms from section (401 - 457 m).

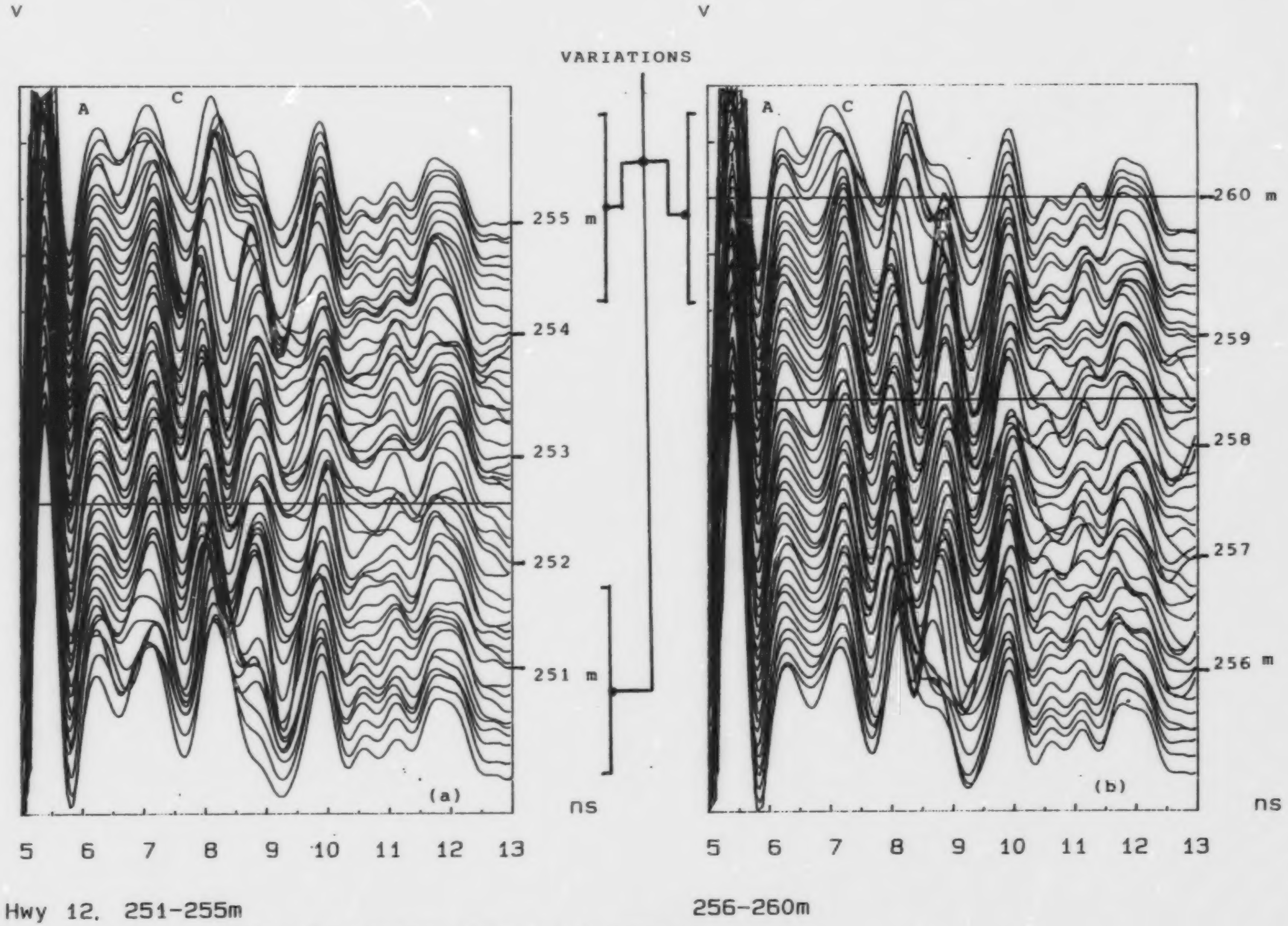


Fig 86: Hwy. 12/400 - STC waveforms from section
(a) 251 - 255 m, (b) 256 - 260 m.

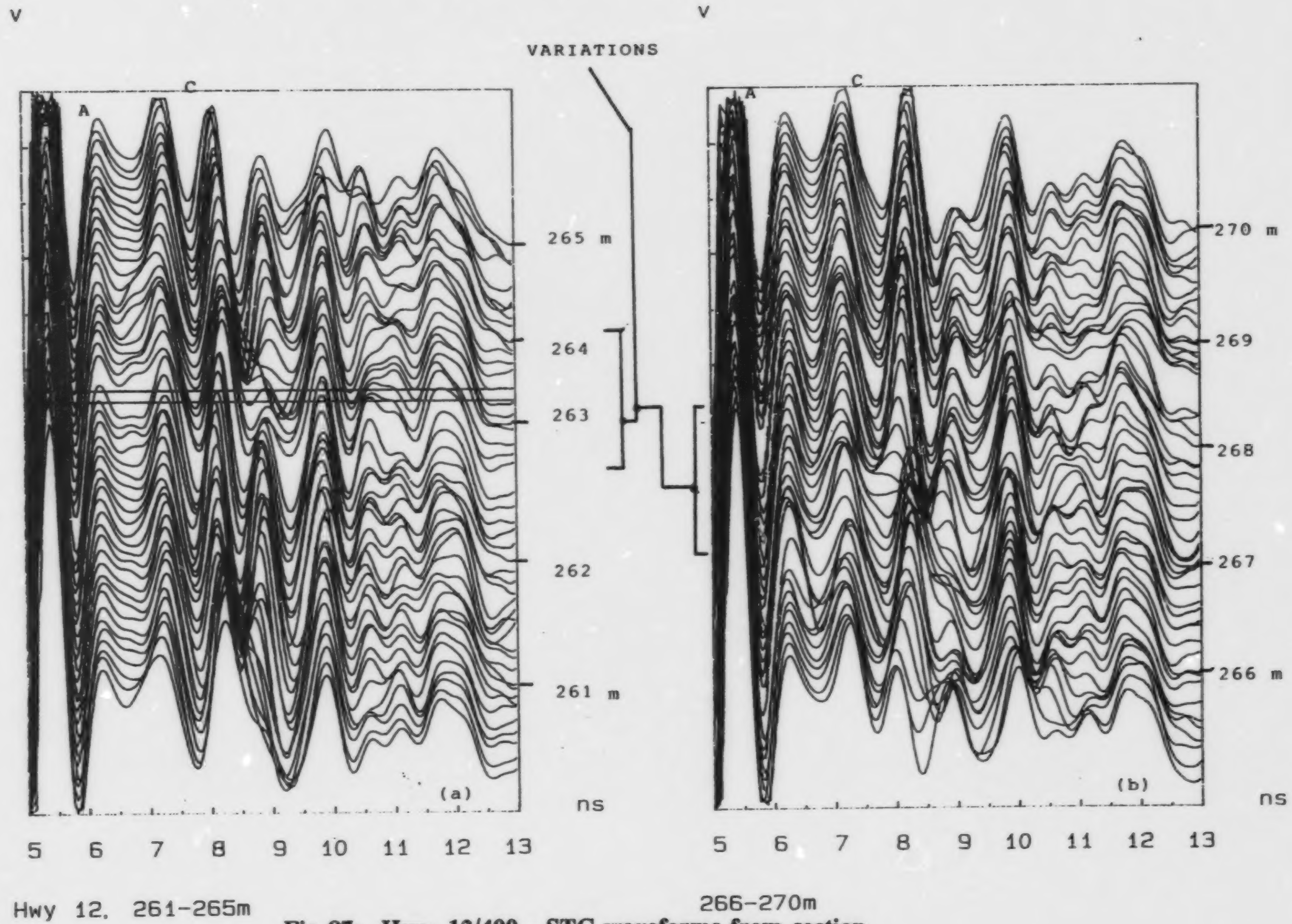


Fig 87: Hwy. 12/400 - STC waveforms from section
(a) 261 - 265 m, (b) 266 - 270 m.

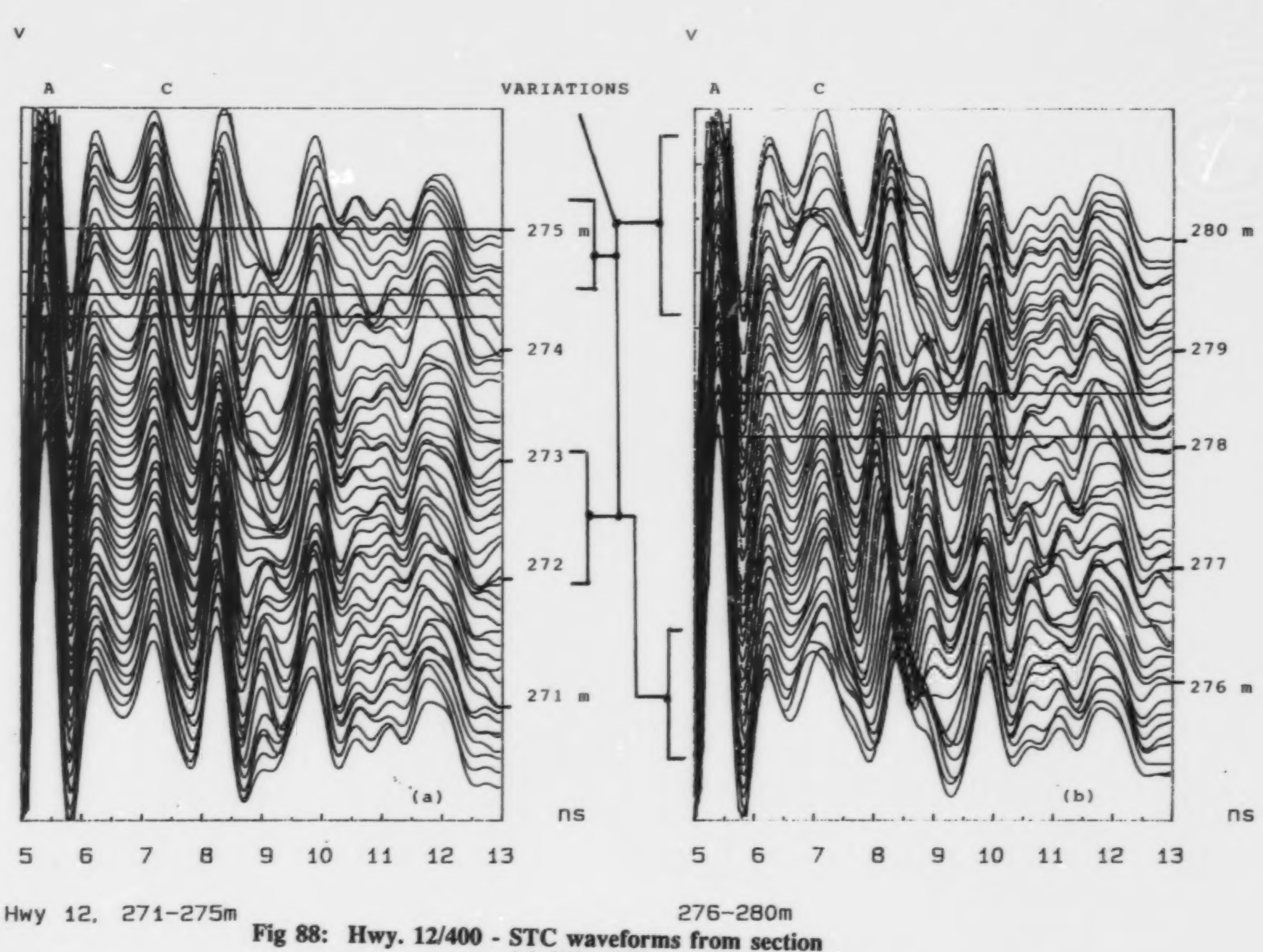


Fig 88: Hwy. 12/400 - STC waveforms from section (a) 271 - 275 m, (b) 276 - 280 m.

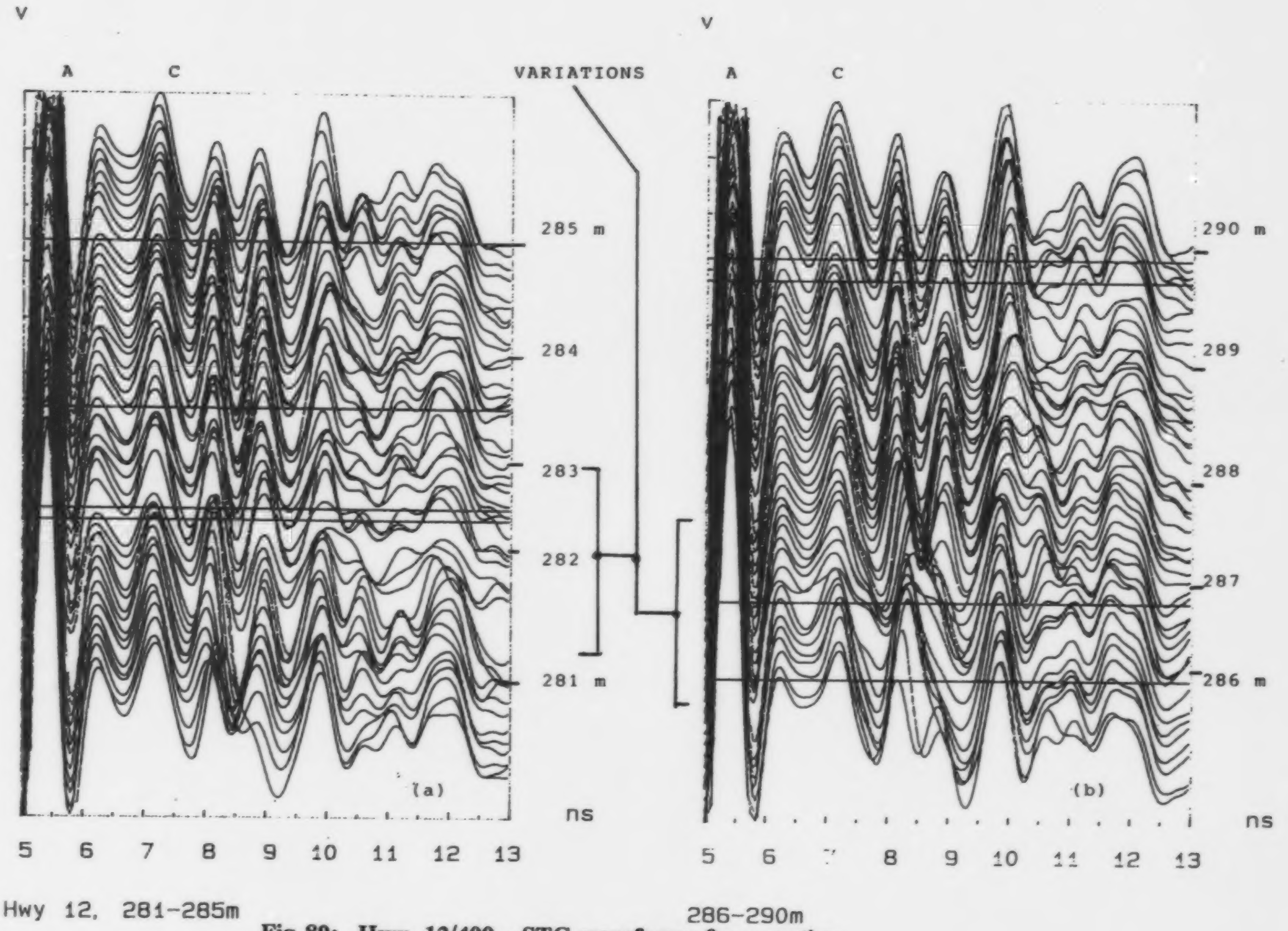


Fig 89: Hwy. 12/400 - STC waveforms from section (a) 281 - 285 m, (b) 286 - 290 m.

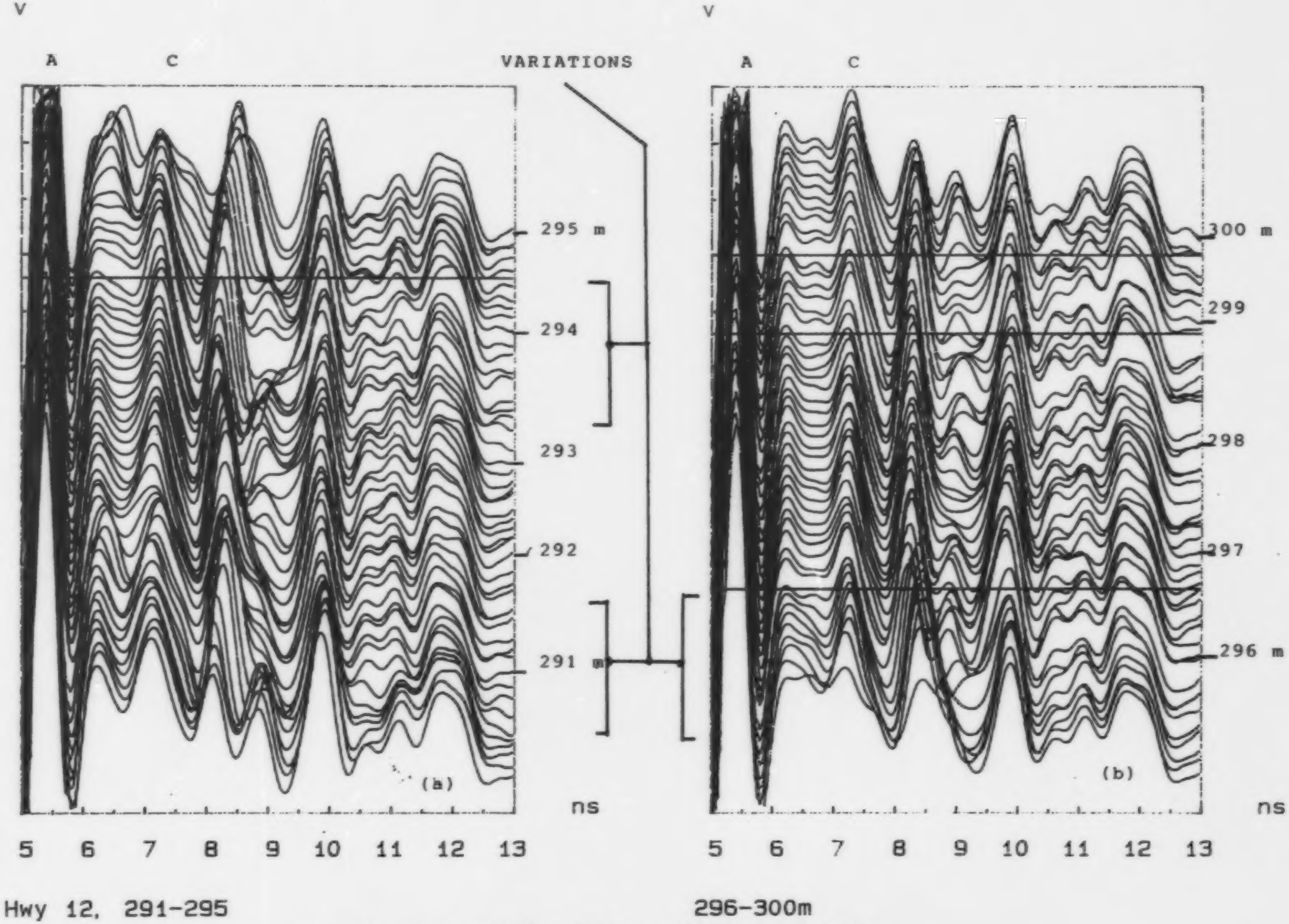


Fig 90: Hwy. 12/400 - STC waveforms from section
(a) 291 - 295 m, (b) 296 - 300 m.

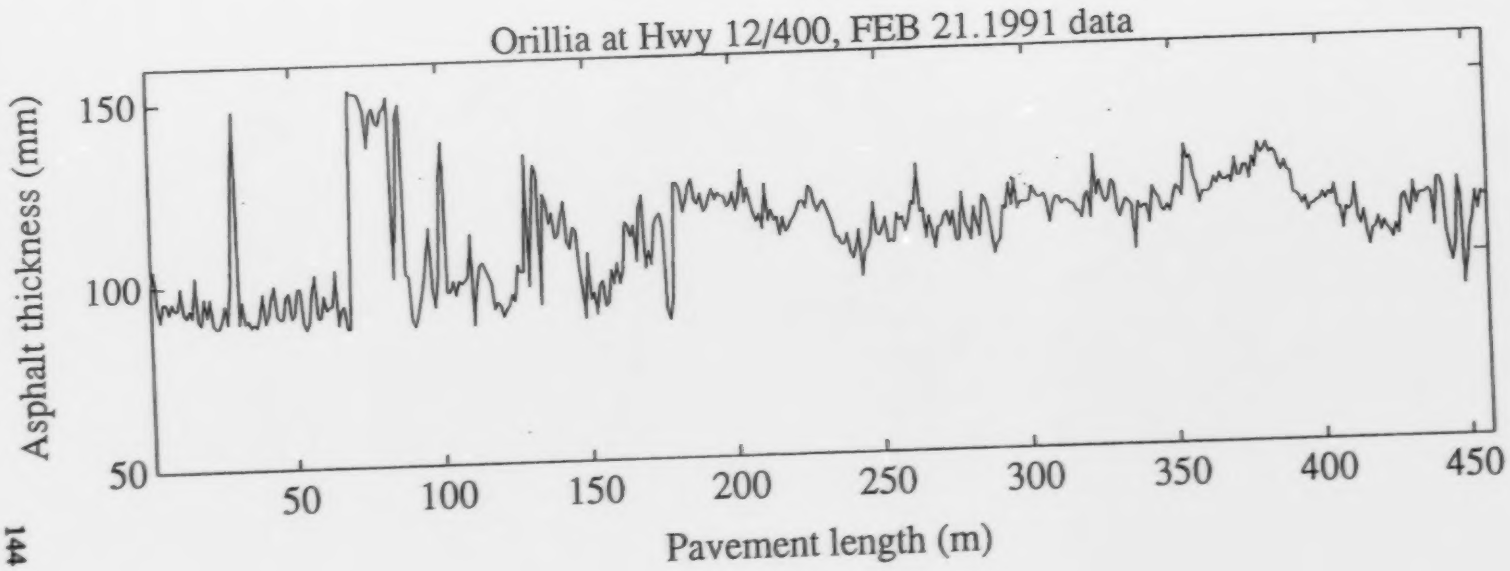


Fig 91: Hwy. 12/400 - Plot of asphalt thickness.

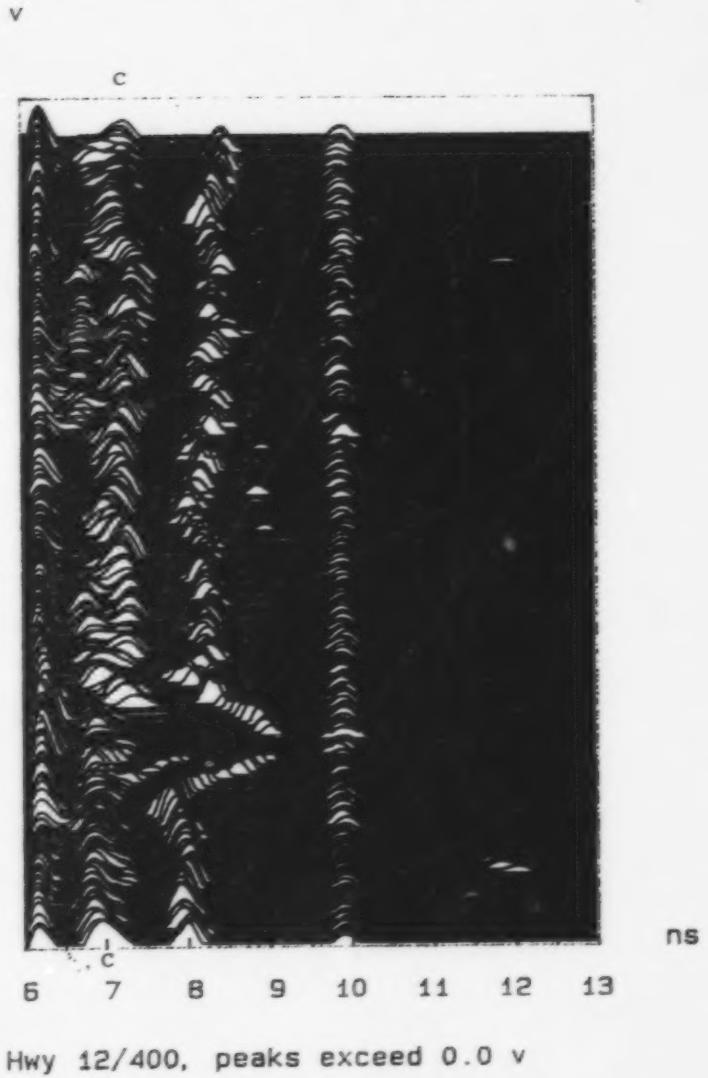
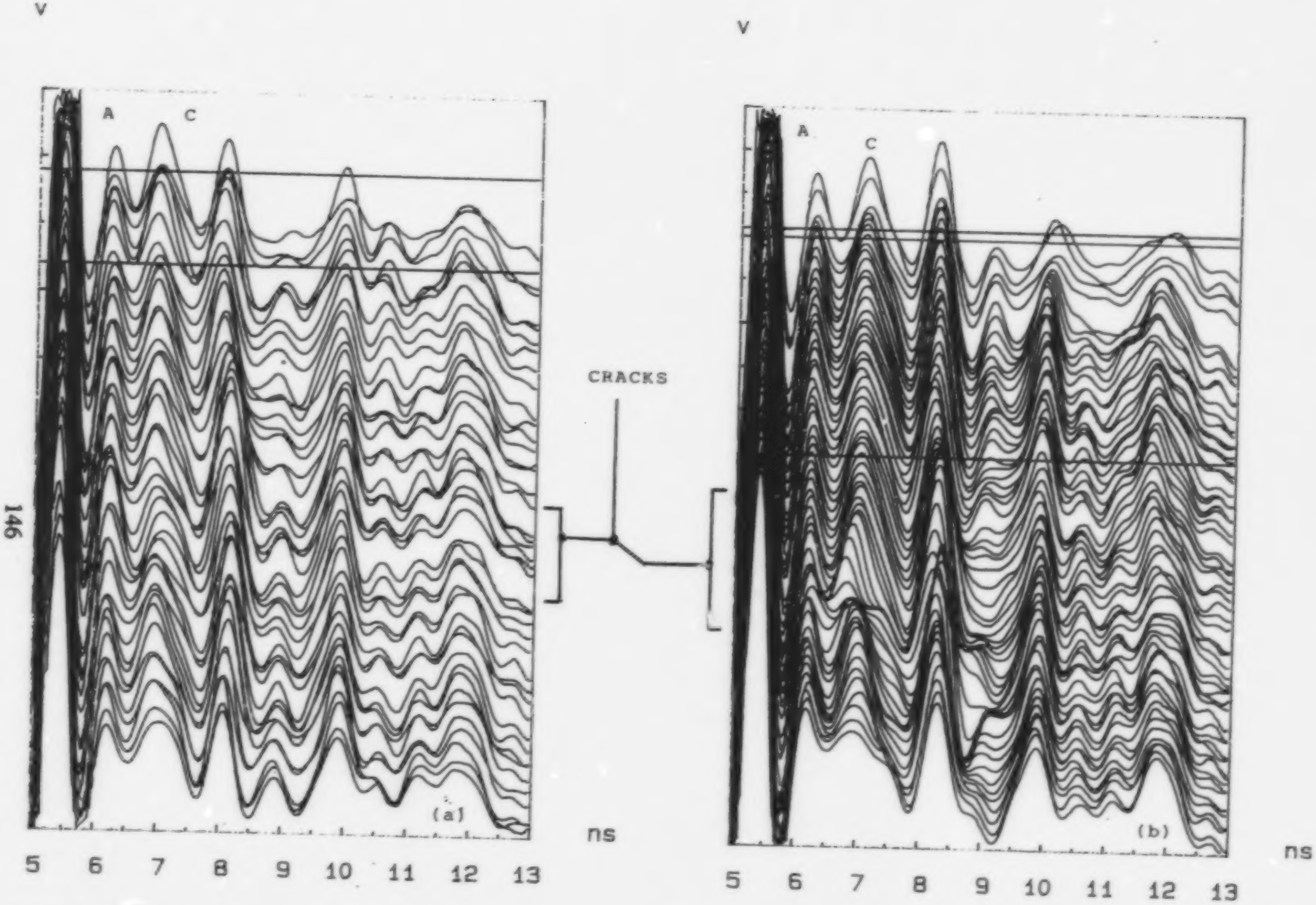


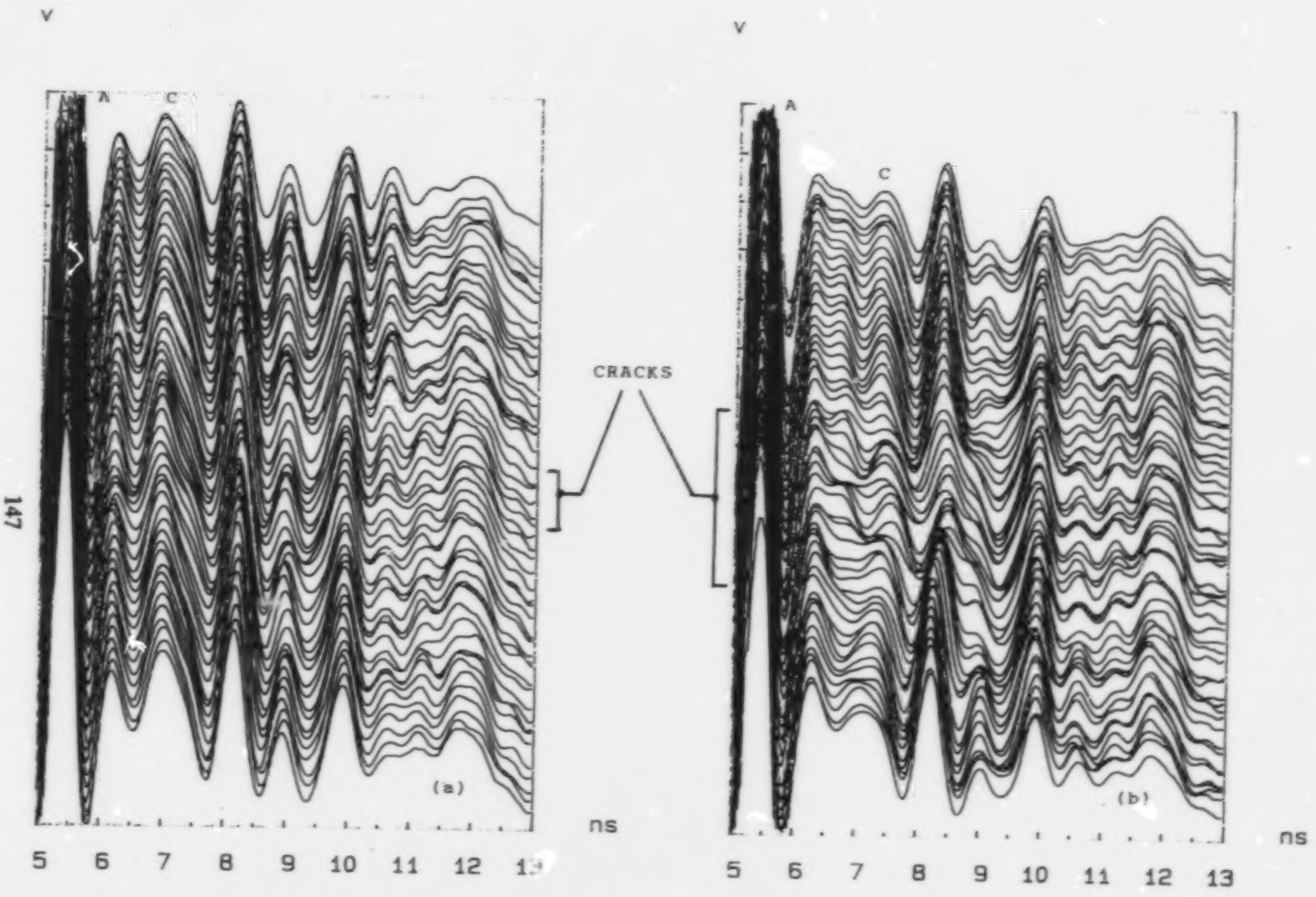
Fig 92: Hwy. 12/400 - Profile plot using STC and 0.0 V threshold.



sealed crack, 13 m, centre lane

sealed crack, 50 m, centre lane

Fig 93: Hwy. 12/400 - (a) Sealed crack at 13 m centre line.
(b) Sealed crack at 50 m centre line.



New crack, 59 m, centre lane

New crack, 88 m, centre lane

Fig 94: Hwy. 12/400 - (a) New crack at 59 m centre line.
(b) New crack at 88 m centre line.

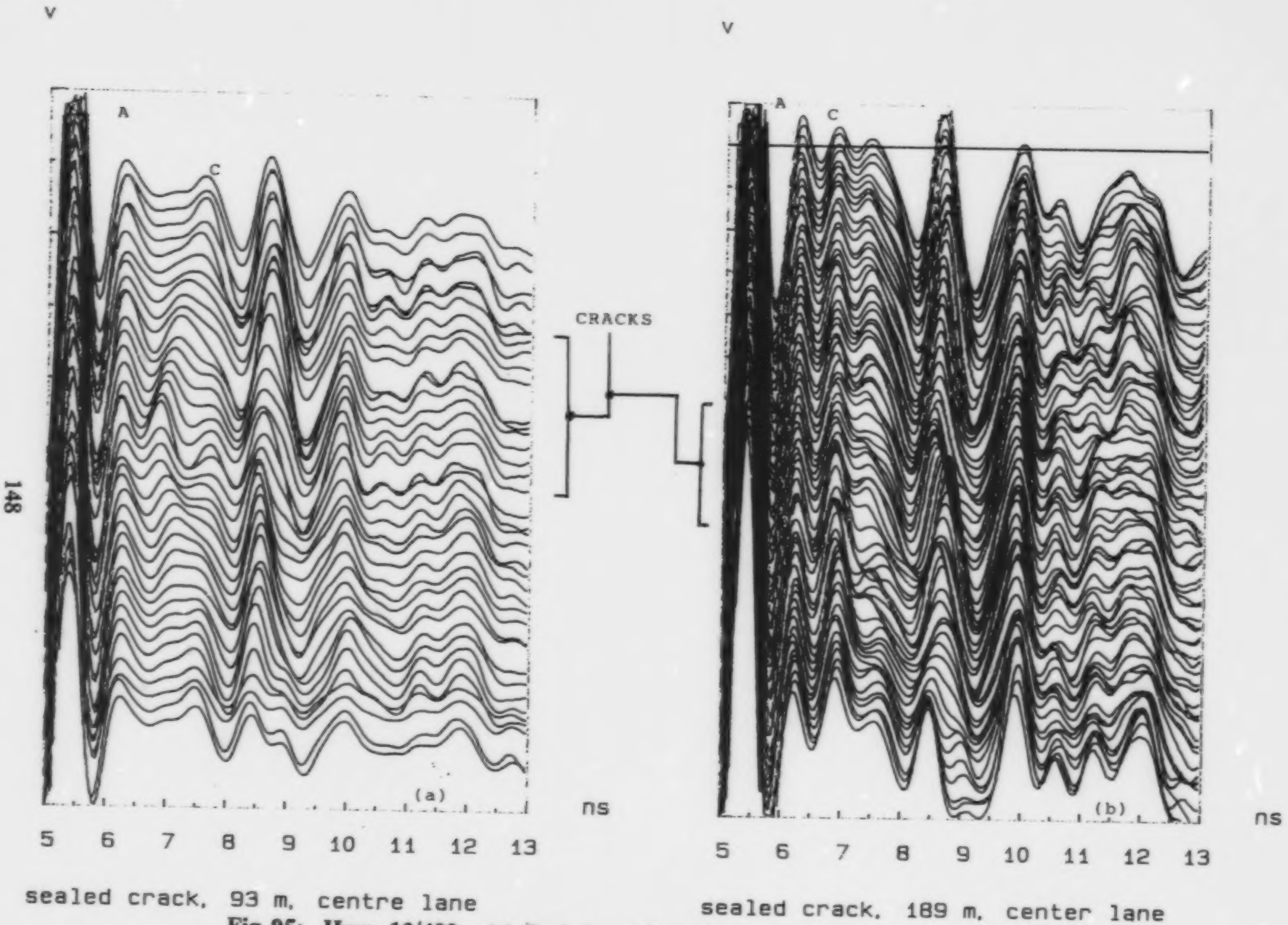
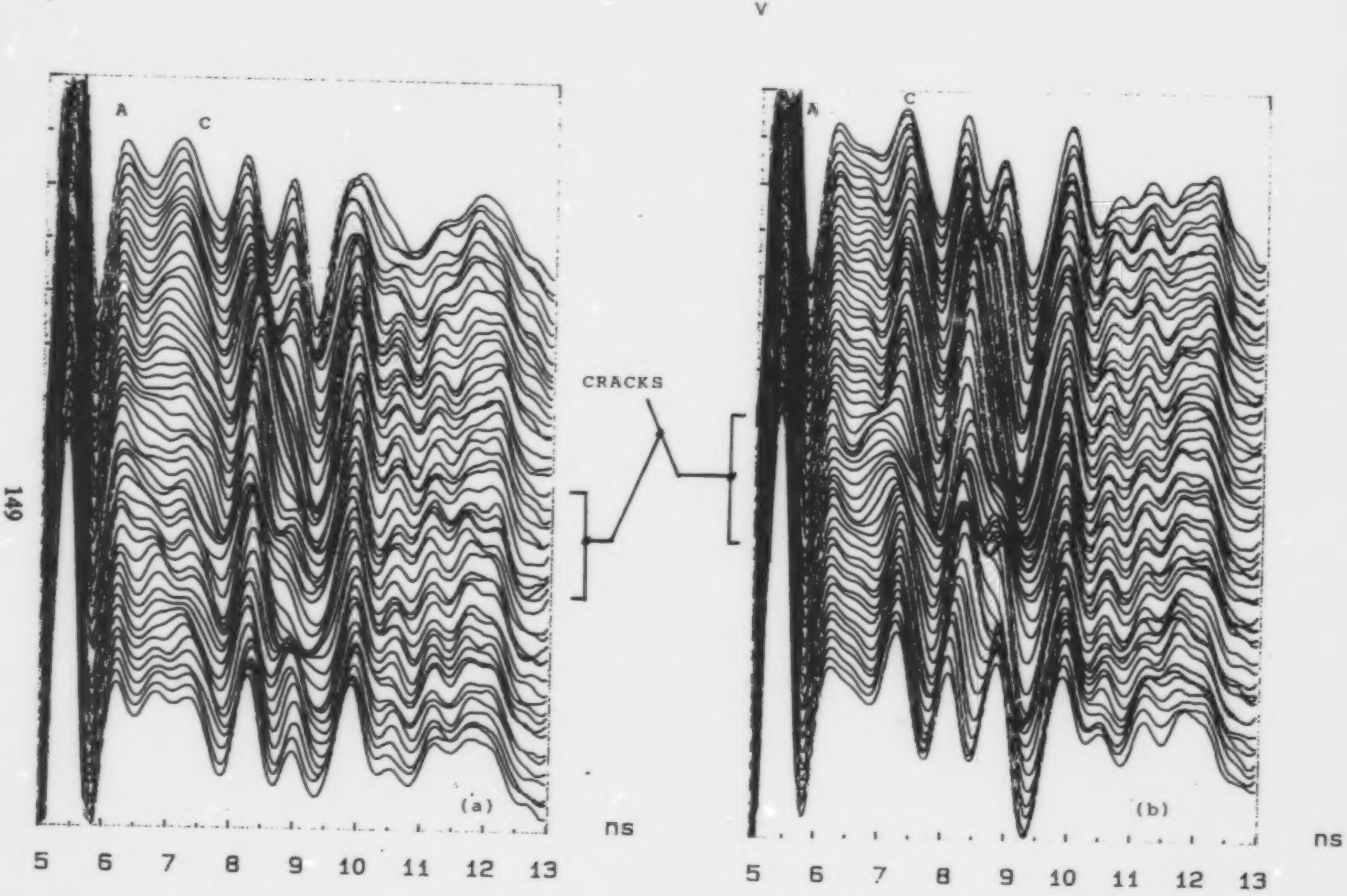


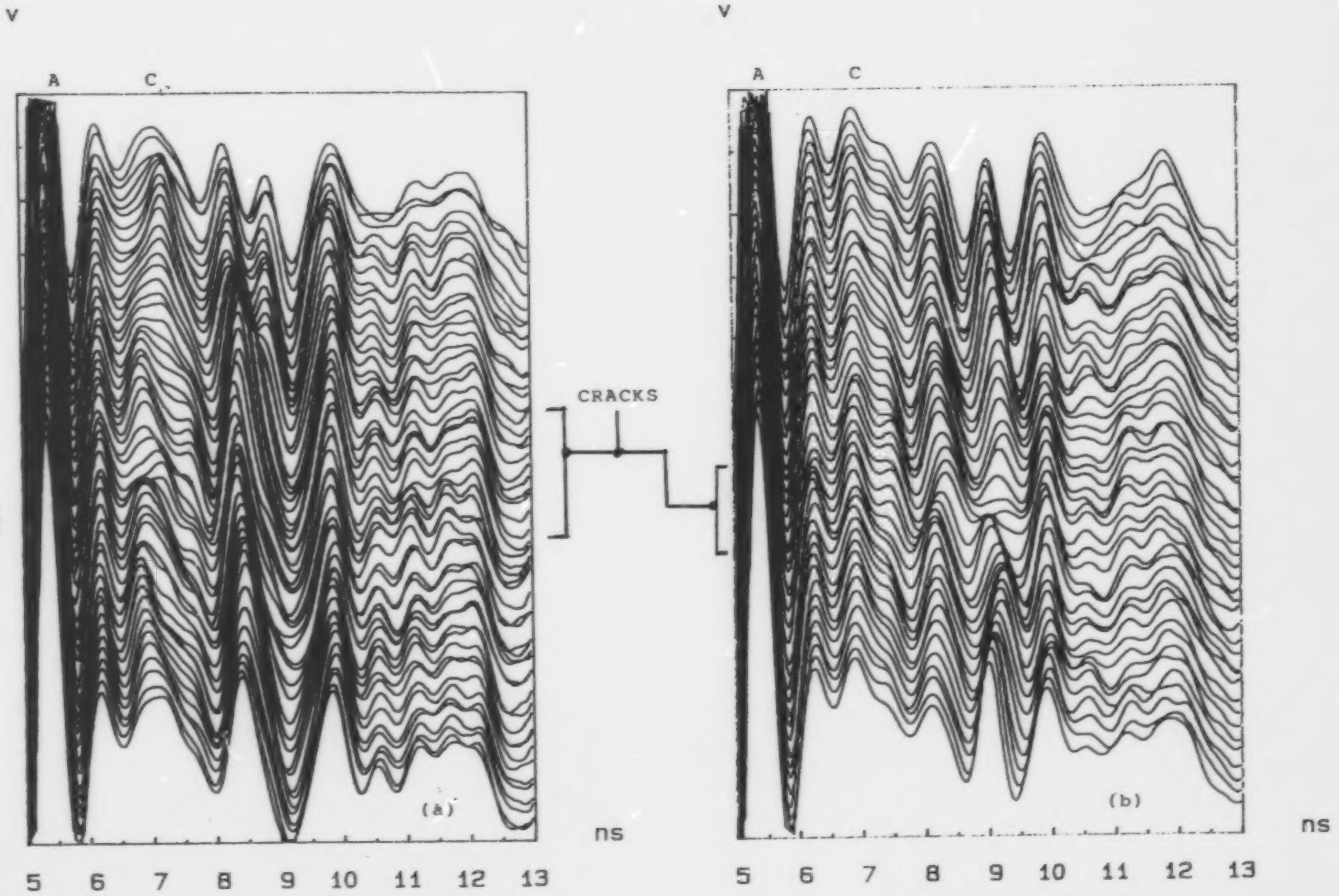
Fig 95: Hwy. 12/400 - (a) Sealed crack at 93 m centre line.
(b) Sealed crack at 189 m centre line.



sealed crack, 235 m. center lane

New crack, 255 m, centre lane

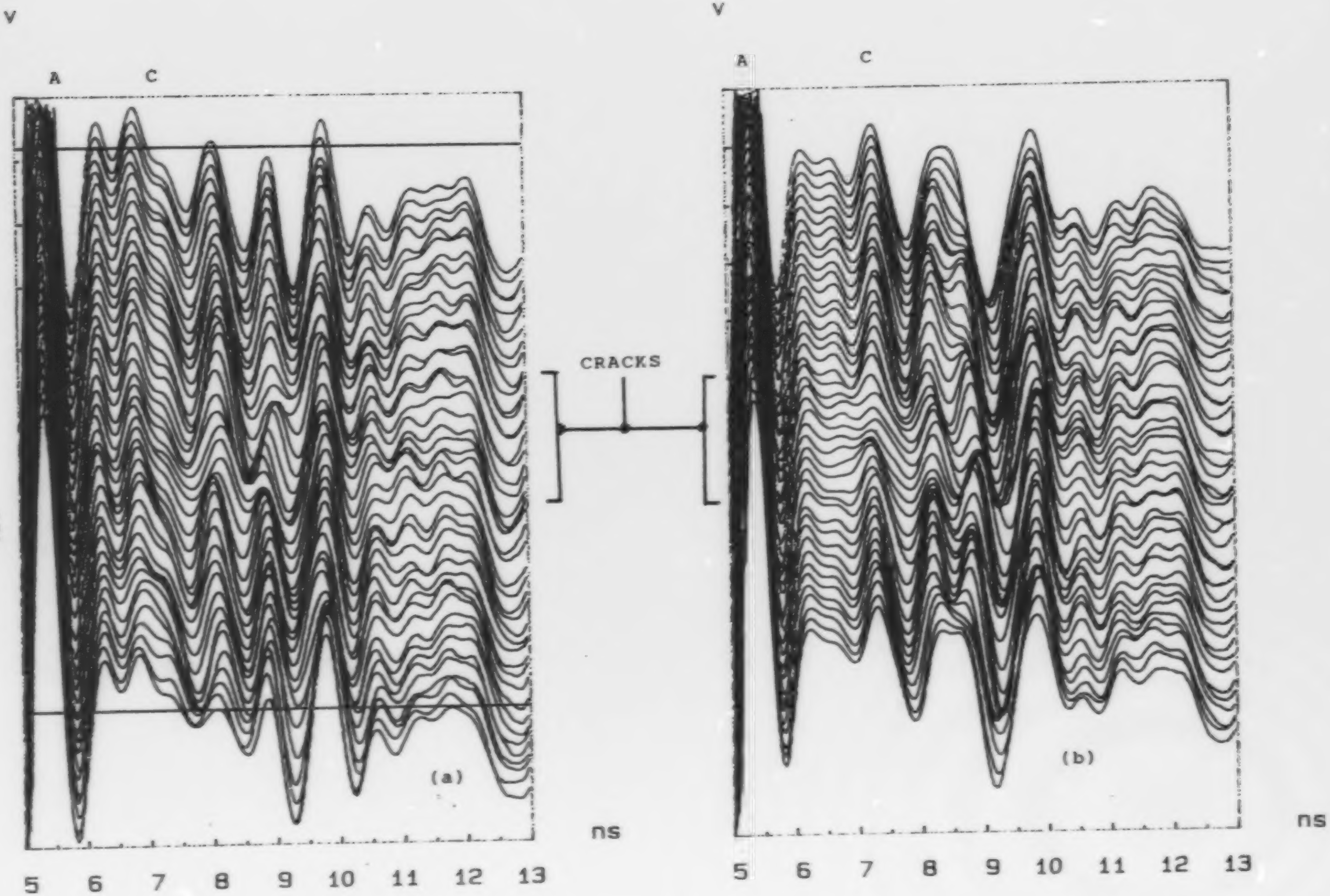
Fig 96: Hwy. 12/400 - (a) Sealed crack at 235 m centre line.
(b) New crack at 255 m centre line.



sealed crack, 274 m, centre lane

New crack, 290 m, edge

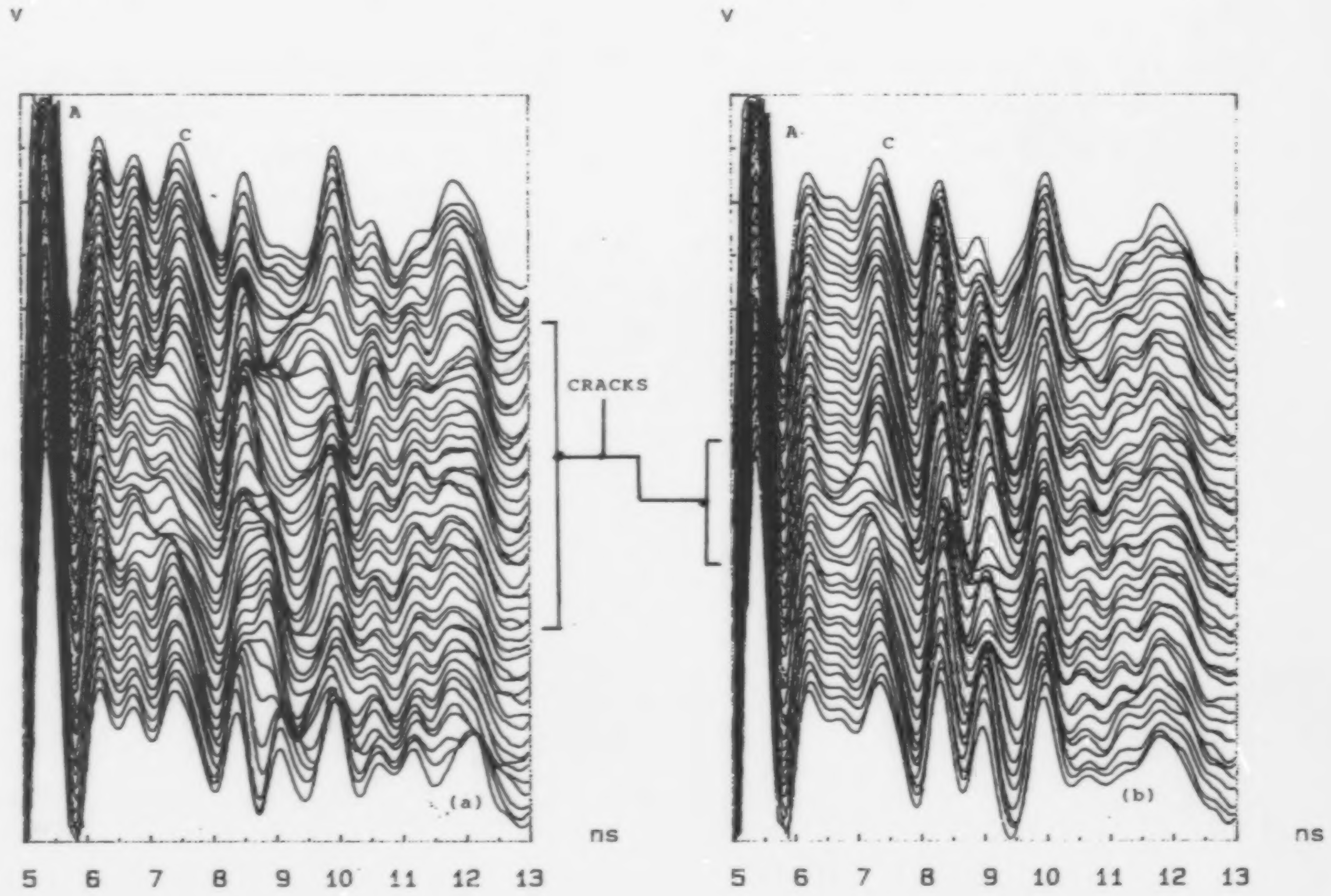
Fig 97: Hwy. 12/400 - (a) Sealed crack at 274 m centre line.
(b) New crack at 290 m edge.



Old crack, 316 m, wheel path

New crack, 328 m, wheel path

**Fig 98: Hwy. 12/400 - (a) Old crack at 316 m wheel path.
(b) New crack at 328 m wheel path.**



Old crack, 346 m, centre lane

New crack, 352 m, centre lane

Fig 99: Hwy. 12/400 - (a) Old crack at 346 m centre line.
(b) New crack at 352 m centre line.

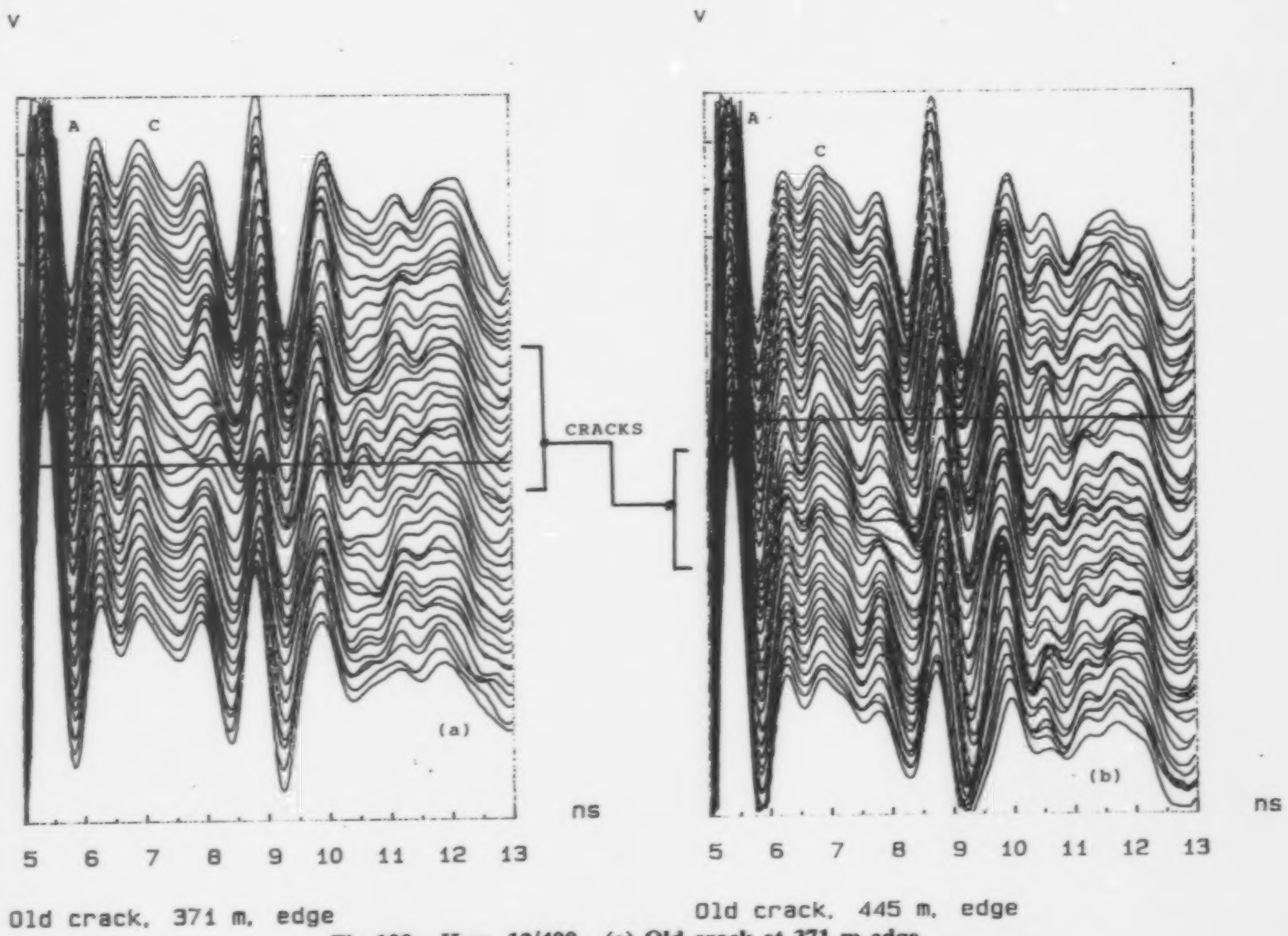


Fig 100: Hwy. 12/400 - (a) Old crack at 371 m edge.
(b) Old crack at 445 m edge.

```
$storage:2

* v.01 JAN 31.91    v.02 FEB 01.91    v.03 FEB 06.91
* v.04 FEB 08.91    v.05 FEB 20.91    v.06 MAR 04.91

* FL PAVE91 FPLATE91 REMIR91 SIGPRO91 PEAKCD91 PEAKS91 TABLE91 /link atlfor;

* PAVEMENT contract

****************************************************************************

      PROGRAM PAVE91

*****************************************************************************

      CHARACTER clearscreen*4, heading*40, error*35, title*60,
     +          fplate*15, calib*15, datfile*15, iready

      PARAMETER ( HEADING = '     [ PAVEMENT SOFTWARE PACKAGE ]',
     +            FPLATE  = 'FPLATE.MTO',
     +            ERROR   = ' ==> input ERROR, please try again',
     +            MAXLINE = 16,
     +            NSAMPLE = 512)

      CHARACTER dfile( MAXLINE )*15
      INTEGER*4 bytesize( MAXLINE ), MAXbytes

      COMMON /BLK1/ ref( NSAMPLE ), ydata( NSAMPLE ), zdata( NSAMPLE )
      COMMON /BLK2/ NUMCYCLE( MAXLINE ), mmASP, ASPdc

**********************
* utilities routines *
**********************
      CLEARSCREEN = char(27)//'['//'2'//'J'         ! clear display
      write(*,*) clearscreen
      CALL GETDAT ( iyr, imon, iday )               ! date stamp
      CALL GETTIM ( ihr, imin, isec, i100th )       ! time stamp
      write(*,10)imon,iday,iyr,ihr,imin,isec,i100th
10    format(1x,'DATE = ',i2,1x,i2,'.',i4,10x,' TIME = ',i2,3(':',i2),/)

*********
* INPUT *
*********
      write(*,'(a,/)') heading
      write(*,'(a)') ' - input SITE name - '
      read(*,'(a)') title

***************
* fifth wheel *  minimum 0.01 m (1 cm)
***************
      CALL FLASH ( clearscreen, heading, title )
20    write(*,'(a)')  '      - FIFTH WHEEL information -'
      write(*,'(a\)') ' input pulse interval (m) [min 0.01 m] : '
      read(*,*) wheel
      if ( wheel .lt. 0.01 ) then
           write(*,'(a,/)') error
           go to 20
      endif

      rangeMIN = wheel * (25600.*2./512.)        ! ONE DMA buffer
      rangeMAX = wheel * (25600.*2./512.)*100.   ! fill up ALL DMA buffer
      write(*,'(1x,/,a)')'                   -  SCAN RANGE -'
30    write(*,'(a)')'            - ALLOWABLE RANGE per PASS - '
      write(*,32)rangeMIN
32    format(1x,' ... MINIMUM range is AT LEAST ',f10.2,' metres ...')
      write(*,34)rangeMAX
34    format(1x,' ... MAXIMUM range is NOT OVER ',f10.2,' metres ...')
      write(*,'(a\)')' input pavement range (m) : '
      read(*,*)range
      if ( range .lt. rangeMIN .OR. range .gt. rangeMAX ) then
           write(*,'(a,/)') error
           go to 30
      endif

      RateMIN = wheel
      RateMAX = wheel * 100.    ! 100 is the maximum dimension for ave
      write(*,'(1x,/,a)')'                 - OUTPUT STEP SIZE -'
40    write(*,42)RateMIN
42    format(1x,' ... MINIMUM step size is ',f10.2,' metres ...')
      write(*,44)RateMAX
44    format(1x,' ... MAXIMUM step size is ',f10.2,' metres ...')
      write(*,'(a\)')' give output step size (m) : '
      read(*,*)step
      if( step .lt. RateMIN .OR. step .gt. RateMAX) then
          write(*,'(a,/)') error
          go to 40
      endif

*******************
* processing mode *
*******************
* YES ==> ON-site processing right after collecting each line
* NO  ==> collect data only and process later from data files
35    write(*,'(1x,/,a\)')'  [PROCESSING MODE] (1)-YES, (0)-NO :'
      read(*,*)ipmode
      if ( ipmode .lt. 0 .or. ipmode .gt. 1 )then
           write(*,'(a\)') error
           go to 35
      endif
```

```fortran

**************************
* core sample (asphalt) *
**************************
      CALL FLASH ( clearscreen, heading, title )
      write(*,'(a)')  '     - ASPHALT core information -'
      write(*,'(a\)') ' give thickness of asphalt core (mm) : '
      read(*,*) asphalt

*****************
* no. of lines *   maximum 16 lines
*****************
      CALL FLASH ( clearscreen, heading, title )
50    write(*,'(a\)') ' number of lines (max 16) to be collected : '
      read(*,*) numline
      if( numline .le. 0 .or. numline .gt. maxline )then
         write(*,'(a,/)') error
         go to 50
      endif

**********************************
* mode: from ANALOG/DIGITAL data *
**********************************
60    write(*,'(1x,/,a\)') ' [mode] 0 - ANALOG, 1 - data files : '
      read(*,*) mode
      if( mode .ne. 0 .and. mode .ne. 1 )then
             write(*,'(a,/)') error
             go to 60
      endif
      IF ( mode .eq. 1 ) THEN
         do I = 1, numline
             write(*,70) I
70           format(1x,/,    ' data file (',i2,') name is : ',\)
             read(*,'(a)') dfile(i)
             write(*,'(a\)') ' number of byte          : '
             read(*,*) bytesize(i)
             bytesMAX = ANINT(range/wheel)*1024
             MAXbytes = int4( bytesMAX )
             if( bytesize(i).gt.MAXbytes)then
                 write(*,72) MAXbytes
72               format(1x,' ---- current file size is limited to ',
     *                       i12, ' bytes')
                 bytesize(i) = MAXbytes
             endif
         enddo
      ENDIF

*=====================================================================
*| FILE = DEBUG.MTO ( 20, UNKNOWN, FORMATTED, WRITE, SIGANAL90+PEAKS90 |
*| open/close                                                          |
*=====================================================================
* create data file  = DEBUG.MTO for DEBUGGING
      write(*,'(/,a\)')' [ DEBUG ] 0-no, 1-yes : '
      read(*,*) isave
      if ( isave .eq. 1 ) then
         OPEN( 20,file = 'DEBUG.MTO',status='unknown',form='formatted' )
         rewind( 20 )
      endif

*===================================================================
*| FILE = CALIB.MTO (10, OLD, UNFORMATTED, READ, FPLATE90+SIGANLAD ) |
*| open/close                                                        |
*===================================================================
* get calibration waveform
      write(*,'(/,a\)')' [ CALIBRATION ] data file name (*.MTO)     : '
      read(*,'(a)') CALIB
      OPEN ( 10, file = calib,  status ='old', form='unformatted' )
             rewind ( 10 )
             read ( 10 ) ( REF ( i ), i = 1, nsample )
      CLOSE ( 10 )

***************************
* flat plate information *
***************************
      CALL FLASH ( clearscreen, heading, title )
80    write(*,'(a\)')' [ FLAT PLATE ] (0)-analog, (1)-file, (2)-input: '
      read(*,*) iplate
      IF( iplate .lt.0 .and. iplate .gt. 2 )then
          write(*,'(a,/)') error
          go to 80

* flat plate amplitude from ANALOG data
          else if ( iplate .eq. 0 ) then
             CALL FLASH ( clearscreen, heading, title )
100          write(*,'(1x,/,a)') '    - FLAT PLATE: check hardware -'
             write(*,'(a)')       ' -**- strike return when ready -**-'
             write(*,'(a\)')      '        or <CTRL-C to abort>     '
             read(*,'(a)') iready
             if( iready .ne. ' ' ) go to 100

* flat plate amplitude from DATA FILE
          else if( iplate .eq. 1 ) then
             write(*,90) fplate
90           format(1x,/,1x,'FLAT PLATE file NAME must be : ',a15)
             write(*,'(a)')       ' -**- strike return if OKay -**-'
             write(*,'(a\)')      '       or <CTRL-C to abort>     '
             read(*,'(a)') iready

* flat plate amplitude from operator input
```

```
          else if ( iplate .eq. 2 ) then
            write(*,'(1x,/,a\)') ' flat plate amplitude (v) is : '
            read(*,*) fpamp
      ENDIF

************
* FPLATE91 *    digitized flat plate signals
************
* call subroutine FPLATE91 to digitize 20 traces of metal plate signal.
      IF( iplate .ne. 2 ) CALL FPLATE91 ( IPLATE, ISAVE, FPAMP )
      write(*,*) ' '
      write(*,'(a)')     ' -**- strike return when ready -**-'
      read(*,'(a)')ready

*=====================================================================
*| FILE = TABLE.MTO ( 30, UNKNOWN, UNFORMATTED, WRITE, SIGNAL90+TABLE90  |
*| open/close                                                            |
*=====================================================================
* create data file = TABLE.MTO for SUMMARY output
      OPEN( 30, file='TABLE.MTO', status='unknown', form='unformatted' )
            rewind( 30 )

**********************
* GET A NEW LINE HERE *
**********************
      DO 200 LINE = 1, NUMLINE

* get ready for radar signal
             write(*,*) clearscreen
             CALL GETTIM ( ihrS, iminS, isecS, i100thS )
             write(*,10) imon,iday,iyr,ihrS,iminS,isecS,i100thS
             write(*,'(a,/)') heading
             write(*,'(1x,a,/)') title
             write(*,*) 'flat plate amplitude = ',fpamp,' volt'
             write(*,*) ' '
             write(*,*) ' -*-*- get LINE number : ',LINE,' -*-*-'

         IF ( mode .eq. 0 ) THEN

110          write(*,'(1x,/,a)')'  - RADAR SIGNAL: check hardware -'
             write(*,'(a)')     ' -**- strike return when ready -**-'
             write(*,'(a\)')    '        or <CTRL-C to abort>    '
             read(*,'(a)') iready
             if( iready .ne. ' ' ) go to 110
             write(*,112) WHEEL
112          format(1x,/,'   sample at every ',f10.6,' m',/)

         ELSE

             datfile           = dfile ( Line )
             NUMCYCLE( Line ) = int2 (bytesize(Line)/int4(1024))

         ENDIF

************
* SIGPRO91 *    subroutine SIGPRO91 to digitized/real signal and process
************
* call subroutine SIGPRO91 to digitize radar data
         CALL SIGPRO91( title, mode, line, datfile, isave, fpamp,
     *                  ipmode, asphalt, wheel, range, step)

         xLong = ANINT( float( numcycle( Line ) ) * wheel )
         Length = INT( xLong )

         open( 90, file = 'PRN')
         write(*, 120) Line, NUMCYCLE( Line ), LENGTH
         write(90,120) Line, NUMCYCLE( Line ), LENGTH
120      format(1x,/,' Line = ',i2,4x,'total TRACE = ',i5,4x,
     *          'bridge LENGTH = ',i5,' metres',/)

         write(*, '(a\)') ' START  time: '
         write(90,'(a\)') ' START  time: '
         write(*, 124) imon,iday,iyr,ihrS,iminS,isecS,i100thS
         write(90,124) imon,iday,iyr,ihrS,iminS,isecS,i100thS
124      format(1x,'DATE = ',i2,1x,i2,'.',i4,10x,'TIME = ',i2,3(':',i2))
         CALL GETTIM ( ihr, imin, isec, i100th )
         write(*, '(a\)') ' FINISH time: '
         write(90,'(a\)') ' FINISH time: '
         write(*, 124) imon,iday,iyr,ihr,imin,isec,i100th
         write(90,124) imon,iday,iyr,ihr,imin,isec,i100th
         close( 90 )
         write(*,*)' '
         write(*,'(a\)') ' -**- strike return when ready -**-'
         read(*,'(a)') ready

200   CONTINUE

      close( 30 )
      if ( isave .eq. 1 ) close ( 20 )

***********
* TABLE91 *  print results in table form
***********
* prepare to print TABLE
      IF ( IPMODE.eq.1 )CALL TABLE91 (TITLE,NUMLINE,FPAMP,ASPHALT,WHEEL,
     *                                 RANGE,STEP)

      write(*,*) ' '
      write(*,'(a\)') ' -**- strike return when ready -**-'
      read(*,'(a)') ready
      CALL FLASH ( clearscreen, heading, title )
      write(*,'(1x,a,/)') ' [ data files information ]'
      write(*,'(1x,a\)') ' SAVE the following DATA FILEs BEFORE the'
      write(*,'(1x,a,/)')' NEXT run'
      write(*,'(1x,a)')' SUMMARY.MTO   (formatted)   : summary'
      write(*,'(1x,a)')' TABLE.MTO     (unformatted) : BKUP summary'

***************
* data files *
***************
      if ( mode .eq. 0 )write(*,'(1x,a)')
     +                 ' drive Es files (binary)    : signal raw'

      IF ( ISAVE .EQ. 1 ) THEN
       write(*,'(1x,a)')' SIGRESDUE.MTO (unformatted) : signal resdue'
       write(*,'(1x,a)')' DEBUG.MTO     (formatted)   : debug'
       if ( iplate .eq. 0 )write(*,'(1x,a)')
     +                 ' FPLATE.MTO    (binary)      : fplate raw'
       if ( iplate .ne. 2 ) then
        write(*,'(1x,a)') ' FPRESDUE.MTO  (unformatted) : fplate resdue'
       endif
      ENDIF

      END

      SUBROUTINE FLASH ( clearscreen, heading, title)
      CHARACTER clearscreen*(*), heading*(*), title*(*)
      write(*,*) clearscreen
      CALL GETDAT ( iyr, imon, iday)
      CALL GETTIM ( ihr, imin, isec, i100th )
      write(*,10) imon,iday,iyr,ihr,imin,isec,i100th
 10   format(1x,'DATE = ',i2,1x,i2,'.',i4,10x,' TIME = ',i2,3(':',i2),/)
      write(*,'(a,/)') heading
      write(*,'(1x,a,/)') title
      RETURN
      END
```

```
$storage:2

* v.01 JAN 31.91

* fl/c FPLATE91.for

* obtain the flat plate reflection

      SUBROUTINE FPLATE91 ( iplate, isave, fpamp )

$INCLUDE:'ATLDEFS.FOR'
$INCLUDE:'ATLERRS.FOR'

      PARAMETER ( NBUFFERS = 1      )  ! no. of data buffers
      PARAMETER ( NBUFSIZE = 512    )  ! data buffer size (WORDS)
      PARAMETER ( NXMBUF   = 1      )  ! no. of XM buffers
      PARAMETER ( NXMSIZE  = 10240  )  ! XM buffer size (words)
      PARAMETER ( N325     = 325    )

      INTEGER*2 STATUS
      INTEGER*2 ADCHANNELS(16), ADGAINS(16)
      INTEGER*2 SCANCOUNT, UNITNUMBER, RELEASEDBUFFER
      INTEGER*2 BUFS(NBUFSIZE,NBUFFERS), BUFNUM(NBUFFERS,2)
      INTEGER*2 XMBUFNUM(NXMBUF)
      INTEGER*2 BLENGTH, TIMEOUT
      INTEGER*2 SAMPLE

      COMMON /BLK1/ ref( NBUFSIZE ), ydata ( NBUFSIZE ), xdata(NBUFSIZE)
      DIMENSION xdata( NBUFSIZE)
      REAL*4 RATE
      CHARACTER key

*  BEGIN PROGRAM
      WRITE(*,'(1x,/,a)') '      - FLAT PLATE -'

****************
* ANALOG DATA * call ATLAB's routines to sample flat plate signal
****************
* for IPLATE = 0 (from tape)
      IF ( IPLATE .EQ. 0 ) THEN

* set A/D hardware parameters
      unitnumber    = 1
      ItrigV        = 100        ! trigger threshold (digital level)
      ItrigC        = 1          ! A/D channel # 1 for trigger
      RATE          = 25000.     ! 25 KHz sampling rate

*  INITIALIZE THE ATLAB SUBROUTINES, select board, reset device
      write(*,'(a)')'  - initialize DT2821 and ATLAB routines -'
      STATUS = ALINIT ()
      STATUS = ALSB (UNITNUMBER)
      STATUS = ALRSET ()

* REQUEST SCAN COUNT, CHANNELS, GAINS AND COMMENTS.
      SCANCOUNT       = 1
      ADCHANNELS(1) = 0   ! A/D channel # 0 for radar signal
      ADGAINS(1)      = 1

* ASSIGN USER BUFFER and link it to buffer transfer list
      STATUS = ALFDL ( BUFS(1,1), BLENGTH )
      STATUS = ALDB( BUFNUM(1,2), BUFS(1,1), NBUFSIZE )
      STATUS = ALLB( BUFNUM(1,2) )

* set XM buffer, note that the size is NXMSIZE
      STATUS = ALAXMB ( XMBUFNUM(1), NXMSIZE )

*  SET THE TIMEOUT RATE BASED ON THE SAMPLING RATE AND THE BUFFER SIZE
      TIMEOUT = ( NINT( REAL(NBUFSIZE)/RATE ) + 1 ) * 2 * NBUFFERS
      STATUS  = ALST ( TIMEOUT )

* set up parameters for data acquisition
      IBUF      = bufnum(1,2)         ! user buffer number
      ICYCLE    = NXMSIZE/NBUFSIZE    ! cycle counter (512s/c)

      write(*,10) ICYCLE
10    format(1x,' - EXPECTED to acquire ',i5,' WAVEFORMS -')

*   BEGIN BURST OPERATION
      write(*,*)' - ACQUIRING DATA [wait] -'

* skip the first 20 triggers
      I = 0
20    I = I + 1

* Trigger is HIGH wait for it to go low
30    STATUS = ALAV ( ItrigC, 1, sample )
      IF ( sample .GT. ItrigV .and. sample .lt. 2048 ) GO TO 30

* Trigger is LOW wait for it to go HIGH
40    STATUS = ALAV ( ItrigC, 1, sample )
      IF ( sample .LE. ItrigV .or. sample .ge. 2048  ) GO TO 40

      IF ( I .LT. 20 ) GO TO 20

* start each cycle of 512 samples here
      icount = 0                           ! counter for 32K words
      I      = 0
50    I      = I + 1

```

```
**************
** TRIGGER **    channel 1
**************
* Trigger is HIGH wait for it to go low
60     STATUS = ALAV ( ItrigC, 1, sample )
       IF ( sample .GT. ItrigV .and. sample .lt. 2048 ) GO TO 60

* Trigger is LOW wait for it to go HIGH
70     STATUS = ALAV ( ItrigC, 1, sample )
       IF ( sample .LE. ItrigV .or. sample .ge. 2048  ) GO TO 70

******************
** RADAR pulse **      channel 0
******************
* set DMA parameters
       STATUS = ALSETA (INTTRIGGER+INTCLOCK,SCANCOUNT,ADCHANNELS,ADGAINS)
       STATUS = ALSF ( RATE )
       STATUS = ALRAD ()

* wait for the user buffer to complete DMA
       STATUS = ALWFC ( ibuf )
       STATUS = ALSTOP ()

* release the buffer from DMA
       STATUS = ALRELB ( UNITNUMBER, RELEASEDBUFFER )

* copy user buffer to XM buffer
       STATUS = ALCB ( RELEASEDBUFFER, XMBUFNUM(1), 0, icount, NBUFSIZE )

* return buffer to DMA
       STATUS = ALRETB ( releasedbuffer )

* update counters
       icount = icount + nbufsize                 ! 32256 yet

* if cycle NE 63, get more
          if ( I .LT. ICYCLE ) go to 50
          write(*,*) ' - no. of waveforms have been acquired = 20 -'

       ELSE

* for IPLATE = 1 (read data file FPALTE.MTO)
          ICYCLE = 20

       ENDIF

       write(*,'(1x,a)')' - processing data (wait) -'

* initialize vectors
       do i = 1, nbufsize
               ydata(i) = 0.0
               xdata(i) = 0.0
       enddo

*=====================================================*
*| FILE =  E:FPLATE.MTO ( 40, UNKNOWN, BINARY, READ ) |
*| open/close                                          |
*=====================================================*
* access data file
       OPEN ( 40, file= 'E:FPLATE.MTO', status='unknown', form='binary' )
               REWIND ( 40 )

*=========================================================*
*| FILE = FPRESDUE.MTO ( 60, UNKNOWN, UNFORMATTED, WRITE ) |
*| open/close                                              |
*=========================================================*
       if ( isave .eq. 1 ) then
       OPEN(60,file ='FPRESDUE.MTO',status='unknown',form='unformatted')
       REWIND ( 60 )
       endif

* get a new cycle of 512 samples
       icount = 0
       iskip  = 0
       DO 200 I = 1, ICYCLE

***********************
* RECOVER ANALOG DATA *
***********************
* copy XM buffer to user buffer
             IF ( iplate.eq.0 ) THEN
               STATUS = ALCB ( XMBUFNUM(1),BUFNUM(1,2),icount,0,NBUFSIZE )

* SAVE flat plate RAW DATA opened in FPLATE90.for
               WRITE ( 40 ) (BUFs( j, 1 ), j = 1, nbufsize )

             ELSE

*******************
* READ DATA FILE *
*******************
* READ flat plate data file opened in FPLATE90.for
               READ ( 40 ) ( BUFs( j, 1 ), j = 1, nbufsize )

             ENDIF

* copy user buffer to vector
             sum    = 0.0
             valmin = 0.0
```

```
              Nsync  = 55
              iflag  = 0

              do j = 1, nbufsize
                    xdata(j) = float( bufs (j,i) ) * 10./2048.
                    sum      = sum + xdata(j)
* locate the first zero crossing sample = nsync
                    if( xdata(j) .lt. valmin .and. iflag .eq. 0 )then
                         iflag = 1
                         Nsync = j
                    endif
              enddo

* locate the reference point (the first valley) which is around 40 samples
* from first zero crossing
              if( iflag .eq. 1 )then
                  do j = Nsync, Nsync + 30
                        if( xdata(j) .le. valmin ) then
                            valmin = xdata(j)
                            Nsync  = j
                        endif
                  enddo
              else
                  Nsync = 55
              endif

* zero average each waveform
* and subtract the internal reflection
              sum = sum/float(nbufsize)
              nref = nbufsize - Nsync + 1
              do j = 1, nref
                       ydata(j) = xdata(Nsync+j-1)-sum
              enddo

* remove internal reflection
              CALL REMIR91 ( maxpks, pkmax )

* SAVE RESDUE data in FPRESDUE.NTO opened in FPLATE90.for
              if ( isave .eq. 1 ) write ( 60 ) ( ydata (j), j=1,nbufsize )


**************************  for surface amplitude LE to 2.5v or
* DETECT CORRUPTED DATA *  peak A is at LE to 120 sample location or
**************************  PEAK A is at GE to 150 sample location
* throw away the bad sampled waveform
              if ( pkmax .le. 2.5 .or.
     *              maxpks .le. 120 .or.
     *              maxpks. ge. 150 ) go to 100

* line up all waveforms wrt to index 135 (5.4 ns)
              mref = 135
              ii   = 0
              do j = maxpks, n325
                    ii = ii + 1
                    k  = mref + ii - 1
                    if ( k .le. n325 ) xdata(k) = ydata(j)
              enddo

              ii = 0
              do j = mref-1, 1, -1
                    ii = ii + 1
                    k  = maxpks - ii
                    if ( k .gt. 0 ) xdata(j) = ydata(k)
              enddo

              do j = 1, n325
                    sdata(j) = sdata(j) + xdata(j)
              enddo

              go to 110

 100          iskip = iskip + 1
              write(*,105)i,pkmax,maxpks
 105          format(1x,' - waveform # ',i2,' is corrupted with PKAmax = ',
     *        f12.6,' and MAXpkA = ',i3)

 110          icount = icount + nbufsize

 200   CONTINUE

       CLOSE ( 40 )
       if ( isave .eq. 1 ) CLOSE( 60 )

       if( iskip.eq.icycle )then
          write(*,'(1x,/,a\)') ' - data are corrupted, abort program - '
          read(*,'(a)')key
       endif

* average over ICYCLE waveforms and get amplitude
       fpamp = 0
       do i = 1, nbufsize
             ydata(i) = sdata(i)/float(icycle-iskip)
             if( ydata(i) .ge. fpamp ) fpamp = ydata(i)
       enddo
       write(*,*)' flat plate amplitude = ', FPAMP

*  TERMINATE ATLAB OPERATIONS
       write(*,*)' - FLAT PLATE DONE -'
```

```

      if( iplate .eq. 0 )then
          STATUS = ALSTOP ()
          STATUS = ALTERM ()
      endif

      RETURN
      END
```

```

$storage:2

* v.01 JAN 31.91   v.02 FEB 22.91

* fl/c REMIR91.for

      SUBROUTINE REMIR91 ( MAXPKA, PKAMAX )

      common /BLK1/ ref(512), ydata(512), zdata(512)
      dimension YRmse(20)

* initialization
      nshf   = 5        ! shift 5 samples to both directions
      nopt   = 100
      n325   = 325

* measure the residue magnitude of the 116 samples by shifting
* waveforms at Nshf samples to each direction
      k = 0
      do I = -nshf, nshf  ! shifting index
             Ymse = 0.0    ! mean sq error
             do J = 1, nopt
                    if( i.lt.0 ) Ydiff = ydata(j)   - ref(j-i)
                    if( i.ge.0 ) Ydiff = ydata(j+i) - ref(j)
                    Ymse = Ymse + (Ydiff*Ydiff)
             enddo
             k = k + 1
             YRmse(k) = (Ymse/float(nopt))**0.5     ! Root mean sq error
      enddo

* search for the mini RMSE
      ERROR = 100.0
      do j = 1, (nshf*2)+1    ! plus 1 => including 0 (at exact line up)
             if( YRmse(j) .le.   ERROR  ) ERROR = YRmse(j)
             if( ERROR    .eq. YRmse(j) ) ishift = j - (nshf+1)
      enddo

* calculate the residue waveform
      DO J = 1, n325
             if( ishift.lt.0 ) zdata(j) = ydata(j)  - ref(j-ishift)
             if( ishift.ge.0 ) zdata(j) = ydata(j+ishift) - ref(j)
      ENDDO

* adjust the residue signal and search for the surface echo peak
      pkamax = 0
      maxpka = 135              ! default value
      DO J = 1,n325
             ydata(j) = zdata(j)
             if ( ydata(j) .ge. pkamax ) then
                  PKAMAX = ydata(j)
                  MAXPKA = j
             endif
      ENDDO

      RETURN
      END
```

```
$STORAGE:2

* v.01 FEB 01.91    v.02 FEB 06.91   v.03 FEB 08.91
* v.04 FEB 11.91    v.05 FEB 21.91

* FL/c SIGPRO91.for

* PAVEMENT's data acquisition

*******************************************************************
       SUBROUTINE SIGPRO91 ( TITLE, MODE, LINE, DATFILE, ISAVE, FRAMP,
    +                  IPMODE, ASPHALT, WHEEL, RANGE, STEP)
*******************************************************************

$INCLUDE:'ATLDEFS.FOR'
$INCLUDE:'ATLERRS.FOR'

       PARAMETER (NBUFFERS  = 1     ) ! no. of data buffers
       PARAMETER (NBUFSIZE  = 512   ) ! data buffer size (WORDS)
       PARAMETER (NXMBUF    = 101   ) ! no. of XM buffers
       PARAMETER (NXMSIZE   = 25600 ) ! XM buffer size (words)
       PARAMETER (MCYCLE    = 100   ) ! data buffer size (waveforms)
       PARAMETER (MAXLINE   = 16    ) ! max 16 passes

       INTEGER*2 ADCHANNELS(16)       ! channel scan list
       INTEGER*2 ADGAINS(16)          ! gains for channels

*  LOCAL VARIABLES
       INTEGER*2 STATUS
       INTEGER*2 SCANCOUNT, UNITNUMBER, RELEASEDBUFFER
       INTEGER*2 TIMEOUT
       INTEGER*2 BUFS(NBUFSIZE,NBUFFERS), BUFNUM(NBUFFERS,2)
       INTEGER*2 BLENGTH
       ~~INTEGER*2 XMBUFNUM(NXMBUF)~~
       INTEGER*2 SAMPLE
       INTEGER*4 IFULL, I64Kw, inewXM, isumASP, IXMBUF(NXMBUF)
       INTEGER*4 Nwave, NoWAVE

       CHARACTER TITLE*(*), RFILE(MAXLINE)*15, DATFILE*15, dfile*15

       REAL*4 RATE

       common /BLK1/ ref(NBUFSIZE), ydata(NBUFSIZE), zdata(NBUFSIZE)
       common /BLK2/ NUMCYCLE( MAXLINE ), mmASP, ASPdc

       dimension wdata( Nbufsize, Mcycle ), mxC( Mcycle )

* store RAW data on DRIVE E:
       DATA RFILE(1) / 'E:LINE1.MTO'/,   RFILE(2)/'E:LINE2.MTO'/
       DATA RFILE(3) / 'E:LINE3.MTO'/,   RFILE(4)/'E:LINE4.MTO'/
       DATA RFILE(5) / 'E:LINE5.MTO'/,   RFILE(6)/'E:LINE6.MTO'/
       DATA RFILE(7) / 'E:LINE7.MTO'/,   RFILE(8)/'E:LINE8.MTO'/
       DATA RFILE(9) / 'E:LINE9.MTO'/,  RFILE(10)/'E:LINE10.MTO'/
       DATA RFILE(11)/'E:LINE11.MTO'/,  RFILE(12)/'E:LINE12.MTO'/
       DATA RFILE(13)/'E:LINE13.MTO'/,  RFILE(14)/'E:LINE14.MTO'/
       DATA RFILE(15)/'E:LINE15.MTO'/,  RFILE(16)/'E:LINE16.MTO'/

* get data from data files
       IF( MODE .EQ. 1 ) GO TO 200

***************
* ANALOG DATA *  use ATLAB's routines
***************
* set threshold's digital level for analog data
       UNITNUMBER = 1
       IsyncV     = 100        ! line sync threshold
       I5thwV     = 100        ! fifth wheel threshold
       ItrigV     = 100        ! trigger threshold

       IsyncC     = 3          ! A/D channel # 3 for sync
       I5thwC     = 2          ! A/D channel # 2 for 5th wheel
       ItrigC     = 1          ! A/D channel # 1 for tigger

       RATE       = 25000.     ! sampling rate

*  BEGIN PROGRAM
       write(*,*) '          - DART data acquisition - '
       write(*,*) '  can digitize 15Mb (max) data using DMA burst mode'
       write(*,*) '         each radar waveform has 512 samples'
       write(*,*) ' '

*  Report Maximum Capacity of the system
       i64Kw=int4(nxmsize)*2       ! each XM-buffer = 51200 words
       iFull=int4(nxmbuf-1)*i64Kw ! fill up 100 XM-buffers = 5.12Mw
       write(*,60) iFULL/NBUFSIZE, float(ifull/nbufsize)*wheel
60     format(1x,' - EXPECT to acquire maximum ',i10,' WAVEFORMS -',/,
    +         2x,'   or equivalent to ',f10.1,' m bridge length',/)

*  INITIALIZE THE ATLAB SUBROUTINES, select board, reset device
       write(*,*)' - initialize DT2821 and ATLAB routines [wait] - '
       STATUS = ALINIT ()
       STATUS = ALSB (UNITNUMBER)
       STATUS = ALRSET ()
       STATUS = ALSF ( RATE )

* REQUEST SCAN COUNT, CHANNELS, GAINS AND COMMENTS.
       SCANCOUNT = 1
       ADCHANNELS(1)=0            ! A/D channel # 0 for radar signal
       ADGAINS(1) = 1
```

```

* DECLARE USER BUFFER
        STATUS = ALFDL ( BUFS(1,1), BLENGTH )
        STATUS = ALDB ( BUFNUM(1,2), BUFS(1,1), NBUFSIZE )
        STATUS = ALLB ( BUFNUM(1,2) )

* set XM buffer, note that the size is NXMSIZE*2
        do i=1,nxmbuf
              STATUS = ALAXMB ( XMBUFNUM(i), NXMSIZE*2 )
        enddo

*  SET THE TIMEOUT RATE BASED ON THE SAMPLING RATE AND THE BUFFER SIZE
        TIMEOUT =(NINT(REAL(NBUFSIZE)/RATE)+1)*2*NBUFFERS
        STATUS = ALST ( TIMEOUT )

***********
** SYNC **  channel 3
***********
* wait for line SYNC channel 3 to go HIGH
        write(*,*)' - line SYNC is NOT READY  [wait] -'
50      STATUS = ALAV ( IsyncC, 1, sample )
        if(sample .lt. IsyncV .or. sample .ge. 2048 ) GO TO 50
        write(*,*)' - line SYNC is now READY -'        ! line SYNC is HIGH

* BEGIN BURST OPERATION
        write(*,*)' - ACQUIRING DATA [wait] -'

        IBUF  = bufnum(1,2)                 ! user buffer number
        LIMIT = NXMSIZE                     ! 25600 samples
        ICYCLE= (NXMSIZE/NBUFSIZE)*2        ! cycle counter (512s/c)
        Nwave = 1                           ! count total waves sampled
        WaveNo= ANINT(range/wheel)          ! maximum # of waves expected
        NoWave= int4( WaveNo )              ! obtain from input in PAVE91

* START a NEW XM-BUFFER
        IXM    = 2        ! initial XM-buffer

70      CONTINUE
        inewXM =0         ! inewXM = XM-buffer counter
        icount =0         ! icount = counter for 25K words
        iflag  =0         ! iflag  = flag for over 25K words

* START each CYCLE of 512 samples here
        I = 1
80      CONTINUE

****************
** 5th WHEEL **     channel 2
****************
* Software count of 5th wheel pulses
            NoWHEEL= NINT( wheel * 100.0 )
            iWHEEL = 0
85          iWHEEL = iWHEEL + 1

* FIFTH wheel pulse is HIGH wait for it to go LOW
90          STATUS = ALAV ( I5thwC, 1, sample )
            if( sample .GT. I5thwV .and. sample .lt. 2048 ) GO TO 90

* check for line SYNC is still HIGH otherwise stop
100         STATUS = ALAV ( IsyncC, 1, sample )
            if( sample .lt. isyncV .or. sample .ge. 2048 )go to 150

* FIFTH wheel pulse is LOW wait for it to go HIGH
            STATUS= ALAV ( I5thwC, 1, sample )
            if( sample .LE. I5thwV .or. sample .ge. 2048 ) GO TO 100

* Check whether 5th wheel = pulse count
            IF ( (wheel.ne.0.10) .AND. (wheel.ne.1) .AND. (wheel.ne.10.)
     +             .and.
     +      ( iWHEEL .LT. NoWHEEL ) )GO TO 85

**************
** TRIGGER **   channel 1
**************
* Trigger is HIGH wait for it to go low
110         STATUS = ALAV ( ItrigC, 1, sample )
            if( sample .GT. ItrigV .and. sample .lt. 2048 ) GO TO 110

* Trigger is LOW wait for it to go HIGH
120         STATUS= ALAV ( ItrigC, 1, sample )
            if( sample .LE. ItrigV .or. sample .ge. 2048 ) GO TO 120

*****************
** RADAR pulse **       channel 0
*****************
* set DMA parameters
        STATUS=ALSETA( INTTRIGGER+INTCLOCK,SCANCOUNT,ADCHANNELS,ADGAINS)
        STATUS = ALBAD ()

* wait for the user buffer to complete DMA
        STATUS = ALMFC ( ibuf )
        STATUS = ALSTOP()

* release the buffer from DMA
        STATUS=ALRELB(UNITNUMBER,RELEASEDBUFFER)

* copy user buffer to XM buffer
        STATUS=ALCB( RELEASEDBUFFER, XMBUFNUM(ixm), 0, icount, NBUFSIZE)

```

```fortran
* return buffer to DMA
        STATUS=ALRETB(releasedbuffer)

* update counters
        icount      = icount+nbufsize            ! 25600 yet
        inewXM      = inewXM+int4(nbufsize)      ! 51200 yet
        ixmbuf(ixm) = inewXM
        ilastxm     = ixm

* if top 25K XM-buffer filled up then
* transfer these 25K samples to the lower XM buffer
        if((icount.ge.limit).and.(iflag.eq.0))then
           STATUS = ALCB(XMBUFNUM(ixm),XMBUFNUM(ixm),0,icount,icount)
           icount = 0
           iflag  =1
        endif

**********
** SYNC **   channel 3
**********
* detect line sync low
        STATUS = ALAV ( IsyncC, 1, sample )
150     if( sample .lt. IsyncV. or. sample .ge. 2048 )then
           ixm=nxmbuf      ! terminate XM-buffer counter
           i=icycle        ! terminate cycle counter
           write(*,*)'  '
           write(*,*)'  - line SYNC is LOW -'
           write(*,*)' - STOP acquiring data -'
        endif

* updata NoWAVE counter
        Nwave = Nwave + 1

* if NoWAVE is not reached and icycle LE MCYCLE, get more
        I= I + 1
        IF ( Nwave .LE. NoWave .and. I .LE. ICYCLE ) go to 80

* if NoWAVE is not reached andu XM is not fill up yet, get more
        IXM= IXM + 1
        IF ( Nwave .LE. NoWave .and. IXM .LE. NXMBUF ) go to 70

* calculate the total no. of sample being acquired
        iFULL=0
        do i=2,ilastxm
             iFULL = iFULL + ixmbuf(i)
        enddo

        DFILE = RFILE(line)           ! save raw data on drive E's files
        NUMCYCLE( Line ) = int(float(iFULL)/512.)
        IXM              = 2          ! current XM-buffer

****************
200     CONTINUE     !  get data from file
****************
* get parameters
        IF ( mode .EQ. 1 ) THEN
             DFILE   = DATFILE
             icycle  = MCYCLE             ! Mcycle waveforms each processing
             ncycle  = numcycle( Line )/icycle   ! calculate num of Mcycle
             reminder= mod( float(numcycle(Line)), float(icycle) )
             Lcycle  = int( reminder )
             ixm     = 0
        ENDIF

        write(*,*)' '
        write(*,*)' - # of CYCLEs digitized = ',numcycle( Line ),' - '
        write(*,*)' - pavement length is = ',numcycle(Line)*wheel,' m -'
        write(*,*)' '
        write(*,*)' - accessing data file ',DFILE,' [wait] -'
        write(*,*)' '

*==================================================================
*| FILE = DFILE = E:Line#.MTO ( 60, UNKNOWN, BINARY, READ/WRITE ) |
*| open/close                                                      |
*==================================================================
        OPEN (60, file=DFILE, status = 'unknown', form = 'binary')
               rewind ( 60 )

*============================================================
*| FILE = SIGRESDUE.MTO ( 80, UNKNOWN, UNFORMATTED, WRITE ) |
*| open/close                                               |
*============================================================
        IF ( isave .eq. 1 ) THEN
             OPEN(80,file='SIGRESDUE.MTO',status='unknown',
     +            form='unformatted')
          rewind ( 80 )
        ENDIF

****************************************
* initialise parameters for processing *
****************************************
* parameters for EACH line
        Nwave   = 0          ! number of waveform per line
        LargeDC = 0          ! clear large DC counter
        aspdc   = 0.0
        SUMdc   = 0.0        ! clear dc values
        write(*,*) ' '

* parameters for AVERAGE THICKness and CONDITIons
```

```
        isumASP  = 0        ! asphalt parameters
        mmASP    = 0
        minASP   = 500
        maxASP   = 0
        icorrupt = 0

* Output table step size iRATE cannot more then Mcycle
        iRATE    = NINT(step/wheel)
        istep1   = 0
        istep2   = 0

        monoASP  = 0
        iBAD     = 0
        kBAD     = 0
        iaveC    = 0
        iLL      = 0

*************************************
* get NEW XM-buffer for ANALOG DATA *
*************************************
130     CONTINUE

        IF ( mode .eq. 0 ) THEN

* ANALOG data
* calculate individual XM-buffer length and left over
                if(ixmbuf(ixm).ge.int4(LIMIT))then
                   ibegin=LIMIT          ! first sample
                   ichunk=LIMIT          ! number of samples each time
                else
                   ibegin=0
                   ichunk=int2(ixmbuf(ixm))
                endif

* transfer lower XM(ixm) to upper XM(1)
                STATUS= ALCB ( XMBUFNUM(ixm),XMBUFNUM(1),ibegin,0,ichunk )

* get a new cycle of 512 samples
                icount = 0
                iflag  = 0
                left   = 0
                icycle = int(float(ixmbuf(ixm))/512.)

        ELSE

* for DATA FILE
                if ( ixm .eq. ncycle ) icycle = Lcycle   ! the reminding bits
                if ( icycle .le. 0 ) go to 400
        ENDIF

******************
* process signal *
******************
        DO 500 I = 1, ICYCLE

                Itrace = I              ! current cycle counter
                Nwave  = Nwave + 1      ! current line waveforms counter

                write(*,300) Line, Nwave, itrace
300             format(1H+,1x,' Line = ',i2,2x,' current = ',i5,2x,
     *                 ' cycle = ',i5)

****************
* get the data *
****************
                IF ( mode .EQ. 0 ) THEN

* for ANALOG data
                   STATUS=ALCB(XMBUFNUM(1),BUFNUM(1,2),icount,0,NBUFSIZE)

************
* RAW data *
************
* SAVE the RAW data on DRIVE E:'s,  data files opened in SIGPRO91.for
                   WRITE (60)(bufs(j,1),j=1,nbufsize)

                ELSE

* read data from files opened in SIGPRO91.for
                   READ ( 60 ) (bufs(j,1),j=1,nbufsize)

                ENDIF

******************************
* remove internal reflection *
******************************
* sync the reference point for removing internal reflection
                sum    = 0.0
                Nsync  = 55
                valmin = 0.0
                izero  = 0

                do j = 1, nbufsize
                     ydata(j) = 0.0
                     zdata(j) = float(bufs(j,1))*10./2048.
                     sum      = sum + zdata(j)
                     if ( zdata(j) .lt. valmin .and. izero .eq. 0 ) then
                          izero  = 1
                          Nsync  = j
                   endif
              enddo

              if ( izero .eq. 1 ) then
                   do j = Msync, Msync + 30
                          if( xdata(j) .le. valmin ) then
                              valmin = xdata (j)
                              Msync = j
                          endif
                   enddo
              else
                   Msync = 55
              endif

              sum  = sum/float(nbufsize)
              nref = nbufsize - Msync + 1
              do j = 1, nref
                   ydata(j) = xdata(Msync+j-1) - sum
              enddo

* remove internal reflections
            CALL REMIR91 ( maxpha, phamax )

*************
* SIGRESDUE *
*************
* for ( SIGRESDUE.MTO ) opened in SIGNAL90.for
            if ( isave .eq. 1) write( 80 )( ydata(j), j = 1, nbufsize )

****************
* CHECK IPMODE *
****************
            IF ( IPMODE .eq. 1 ) THEN   ! for YES mode

*****************************************
* parameters for IRATE waveforms averaging *
*****************************************
            istep2   = istep2 + 1
            irate2   = irate

            Nave     = ( numcycle(Line)/iRATE2 ) * iRATE2
            if ( Nwave .gt. Nave ) iRATE2 = ( numcycle(line) - Nave )

            do j = 1, nbufsize
                 wdata( j, istep2 ) = ydata(j)
            enddo

            dcASP = 6.22
            CORE  = asphalt
            CALL PEAKC91( fpamp, maxpha, dcASP, CORE, LocC)

            mxC( istep2 ) = LocC

            if ( LocC .ne. 999 ) then
                 iaveC = iaveC + LocC
            else
                 iLL   = iLL   + 1
            endif

            IF ( ISTEP2 .EQ. IRATE2 ) THEN

                 if ( istep2 .ne. iLL ) then
                      iaveC = iaveC/(istep2 - iLL)
                 else
* if istep2 = iLL  then iaveC = 999 in PEAKS91
                      iaveC = 999
                 endif

                 LocC1 = 0
                 do J = 1, istep2
                        if ( iaveC .ne. 999 .and. mxC(J) .ne. 999 )then
                             idiff = ABS ( iaveC - mxC(J) )
                             LocC1 = LocC1 + idiff
                        endif
                 enddo

                 if ( istep2 .ne. iLL ) then
                      LocC1 = LocC1/(istep2 - iLL)
                      if ( LocC1 .eq. 0 ) LocC1 = 5
                      LocC2 = LocC1
                 endif

                 DO 550 J = 1, istep2

                       do k = 1, nbufsize
                             ydata (k) = wdata( k,j )
                       enddo

                       i10count = Nwave - istep2 + J

                       CALL PEAKS91 ( fpamp, i10count, mxC(j), iaveC,
     *                                LocC1, LocC2, permasp, isave)

* calculate sum/min/max ASPHALT thickness of current line
                       if ( mmASP .ne. 999 ) then
                            isumASP = isumASP + int4( mmASP )
                            if( mmASP .le. minASP ) minASP = mmASP
                            if( mmASP .ge. maxASP ) maxASP = mmASP
                       else
```

```
                             iCORRUPT = iCORRUPT + 1
                        endif

* calculate sum of dielectric constant of asphalt
                        if(permASP .gt. 0.0 .and. permASP .le. 15.)then
                           sumDC = sumDC + permASP
                        else
                           largeDC = largeDC + 1
                        endif

* AVERAGE for output
                        iSTEP1 = iSTEP1 + 1      ! count 10 cm averaging

                        if( istep1.le.iRATE2 .and. mmASP.ne.999 ) then
                            moneasp     = moneasp + mmASP
                        else
                            iBAD = iBAD + 1
                        endif
                        if( istep1.le.iRATE2 .and. permASP .le. 15 ) then
                            aspdc = aspdc + permASP
                        else
                            kBAD = kBAD + 1
                        endif

                        if ( istep1 .eq. iRATE2 ) then
                             if ( iBAD .ne. istep1 ) then
                                  maveASP = moneasp /float( istep1-iBAD )
                             else
                                 maveASP = 999
                             endif
                             if( kBAD .ne. istep1 ) then
                                 dc  = aspdc  /float( istep1-kBAD )
                             else
                                 dc  = 99.99
                             endif

                             istep1   = 0         ! reset counter after i10 = 10
                             iBAD       = 0
                             kBAD     = 0
                             moneASP  = 0
                             ASPdc    = 0.0

* save 1m average thickress ( TABLE.MTO ) opened in MTO90.for
                             WRITE ( 30 ) MAVEASP, DC
                        endif

550               CONTINUE

                  iaveC  = 0
                  istep2 = 0
                  iLL    = 0

             ENDIF    ! (istep2 eq irate2)

             ENDIF    ! ( end of IPMODE check )

* for AMALOG data update XM-buffer counters
      IF ( mode .EQ. 0 ) THEN
          icount=icount+nbufsize                ! update counter

* copy current XM buffer content to XMBUFNUM(1)
          if((icount.ge.limit).and.(iflag.eq.0))then
             left = int(float(ixmbuf(ixm)) - float(limit))
             STATUS=ALCB(XMBUFNUM(ixm),XMBUFNUM(1),0,0,left)
             iflag=1
             icount=0
          endif
      ENDIF

* get next CYCLE
500     CONTINUE

* finish all XM-buffers/or data yet, if not get more
400     IXM = IXM + 1
        IF ( ( IXM .LE. iLASTXM .AND. MODE .EQ. 0 ) .OR.
     *          ( IXM .LE. NCYCLE  .AND. MODE. EQ. 1 ) ) GO TO 130

        if ( isave .eq. 1 ) then
             if ( mode .eq. 1 )close ( 60 )
             close ( 80 )
        endif

*  TERMINATE ATLAB OPERATIONS
        if ( mode. eq. 0 ) then
             STATUS = ALSTOP ()
             STATUS = ALTERN ()
        endif

****************
* CHECK IPMODE *
****************
        IF ( IPMODE .eq. 1 ) THEN   ! for YES mode

*********************************
* calculate AVERAGE parameters *
*********************************
* calculate AVERAGE asphalt thickness and concrete cover
        if ( Nwave .ne. icorrupt ) then
```

```
             iAVEASP  = int2( isumASP /(NWAVE - int4( iCORRUPT )) )
        else
             iAVEASP  = 999
             minASP   = 999
             maxASP   = 999
        endif

* calculate average dielectric constant of asphalt
        if ( Nwave .ne. LargeDC .and. iaveASP .ne. 999 ) then
             ASPdc = sumdc/float( Nwave - largedc )
        else
             write(*,*)' [warning] asphalt dielectric is very large'
             ASPdc = 999.
        endif

* save processed results (TABLE.MTO)  opened in MTO90.for
        write ( 30 ) iaveASP, ASPdc

* output LINE SUMMARY to printer/monitor
      OPEN ( 80, file = 'PRN' )
      write(80,250)title
250   format(1H1,1x,a60)
      write(*, 210) LINE
      write(80,210) LINE
210   format(1x,/,' * LINE # ',i2,' SUMMARY *')
      write(*, 211) Wheel
      write(80,211) Wheel
211   format(1x,'[ Fifth wheel ]           = ',f10.4,' m')
      write(*, 212) RANGE
      write(80,212) RANGE
212   format(1x,'[ Pavement RANGE ]        = ',f10.4,' m')
      write(*, 213) STEP
      write(80,213) STEP
213   format(1x,'[ OUTPUT format ] every = ',f10.4,' m')
      write(*, 216) FPAMP
      write(80,216) FPAMP
216   format(1x,'[ Flat Plate ]            = ',f10.6,' v')
      write(*, 218) ASPdc
      write(80,218) ASPdc
218   format(1x,'[ Dielectric Constant ] ASPHALT = ',f10.6,' average')
      write(*, 222) ASPHALT
      write(80,222) ASPHALT
222   format(1x,'[ Core Sample (mm) ]     ASPHALT = ',f5.1)
      write(*, 224) minASP, maxASP, iaveASP
      write(80,224) minASP, maxASP, iaveASP
224   format(1x,'[ Asphalt (mm) ]  ',5x,'min: ',i3,5x,'maxi: ',i3,
     +              5x,'AVE = ',i3)
      close ( 80 )

      ENDIF   ! (ipmode)

      RETURN
      END
```

```
$STORAGE:2

* v.01 FEB 04.91    v.02 FEB 20.91

* locate preliminary peak C

* fl/c peakC90.for

      SUBROUTINE PEAKC91 ( fpamp, LocA, doASP, ASPHALT, LocC)

      parameter ( NBUFSIZE = 512  )    ! total sample per raw trace
      parameter ( NOPT     = 325  )    ! total sample per corrected trace

      common /BLK1/ ref(NBUFSIZE), ydata(NBUFSIZE), zdata(NBUFSIZE)

*****************
* check BAD DATA *
*****************
* test for corrupted data.
* data set is good for processing if the ratio of fpamp-peakA to fpamp
* is within the bound of 15% to 75%.
      test = ( fpamp - ydata(LocA) ) * 100./fpamp
      IF ( test .gt. 75 .or. test .lt. 15 ) GO TO 100

*****************
* Locate PEAK B *    transient peak
*****************
      peakB = 1.0
      LocB  = LocA + 10      ! default LocB value
      DO J  = LocA, LocA + 15
              if ( ydata(j) .le. peakB ) then
                   peakB = ydata(j)
                   LocB  = j
              endif
      ENDDO

****************************
*  estimate PEAK C WINDOW   *   calculate IEDGE
* using ASPHALT CORE SAMPLE *
****************************
      Cwindow = ( asphalt * ( doASP**0.5 ) )/6.
      IEDGE   = LocA + int( Cwindow )

**********************************
* set threshold for Positive peaks *
**********************************
      THOLD = 0.0          ! examin peaks exceed 0.0 V
      do J  = LocB,NOPT
           if( ydata(j).le.THOLD ) ydata(j) = THOLD
      enddo

*****************
* Locate PEAK C *     asphalt to concrete interface
*****************
      isample = 8
      locLOW = IEDGE - isample                       ! # samples to the left
      locHGH = IEDGE + isample                       ! # samples to the right
      if ( locLOW .le. (LocB+10) ) locLOW = LocB+10  ! LocC cannot be < LocB
      if ( locHGH .ge. nopt ) locHGH = nopt          ! LocC cannot be > Nopt
      LocC  = locLOW
      peakC = -10.0
      DO J = locLOW, locHGH
              if ( ydata(j) .ge. peakC ) then
                   peakC = ydata(j)
                   LocC  = j
              endif
      ENDDO

* search LocC to the LEFT of the window if LocC = locLOW
      IF ( LocC .eq. locLOW ) THEN
           iflag = 0
           j     = locLOW
 10        continue
           if( ydata(j) .ge. ydata(j-1) ) then
               LocC  = j        ! get LocC
               iflag = 1
           endif
           j = j - 1
           if ( j .le. (LocB+10) ) go to 15
           if ( iflag .eq. 0 ) go to 10
 15      continue
      ENDIF

* search LocC to the RIGHT of the window if LocC = locHGH
      IF ( LocC .eq. locHGH ) THEN
           iflag = 0
           j     = locHGH
 20        continue
           if ( ydata(j) .ge. ydata(j+1) ) then
                LocC  = j       ! get Loc C
                iflag = 1
           endif
           j = j + 1
           if ( j .ge. nopt ) go to 25
           if ( iflag .eq. 0 ) go to 20
 25        continue
      ENDIF
      if(ydata(LocC).eq.0.0)go to 100           ! no peak detected set to 999
      go to 200
```

```

***********************
*       report        *
* corrupted waveforms *
***********************
100   CONTINUE
      LocA    = 999
      LocB    = 999
      LocC    = 999

300   CONTINUE

      RETURN
      END

```

```
$STORAGE:2

* v.01 FEB 04.91

* locate peaks A,B and C
* measure asphalt cover

* f1/c PEAKS91.for

      subroutine PEAKS91 ( fpamp, ii0count, mmC, leveC, LocC1, LocC2,
     +                     pcmmASP, Lsave)

      parameter ( NBUFSIZE = 512  )    ! total sample per raw trace
      parameter ( NOPT     = 325  )    ! total sample per corrected trace
      parameter ( MaxLine  =  16  )    ! max 16 Lines per site
      parameter ( dcASP    = 6.2  )    ! estimated DC of asphalt

      common /BLK1/ ref(NBUFSIZE), ydata(NBUFSIZE), sdata(NBUFSIZE)
      common /BLK2/ NUMCYCLE( MAXLINE ), mmASP, ASPdc

******************
* Locate PEAK A *   surface reflection  (air - asphalt interface)
******************
      LocA = 130
      peakA = 0.
      do j = 1,nopt
              if( ydata(j) .ge. peakA ) then
                   LocA = j
                   peakA = ydata(j)
              endif
      enddo

******************
* TEST BAD data *
******************
* test for corrupted data.
* data set is good for processing if the ratio of fpamp-peakA to fpamp
* is within the bound of 15% to 75%.
      test = ( fpamp - peakA ) * 100./fpamp
      IF ( test .gt. 75 .or. test .lt. 15 .or. leveC .eq. 999 )GO TO 100

******************
* Locate PEAK B *    transient peak
******************
      peakB = 1.0
      LocB  = LocA + 10       ! defaul' LocB value
      DO J  = LocA, LocA + 15
               if ( ydata(j) .le. peakB ) then
                     peakB = ydata(j)
                     LocB  = j
               endif
      ENDDO

****************************
* threshold positive peaks *
****************************
      THOLD = 0.0
      do J = LocB, NOPT
            if(ydata(j).le.THOLD)ydata(j) = THOLD
      enddo

******************
* Locate PEAK C *   use leveC, LocC1, LocC2
******************
      locLOW = leveC - LocC1    ! 5 samples to the left
      locHGH = leveC + LocC2    ! 5 samples to the right
      if ( locLOW .le. (LocB+10)) locLOW = LocB+10  ! LocC cannot be < LocB
      if ( locHGH .ge. nopt ) locHGH = nopt     ! LocC cannot be > Nopt
      LocC  = locLOW
      peakC = -10.0
      DO J = locLOW, locHGH
              if ( ydata(j) .ge. peakC ) then
                    peakC = ydata(j)
                    LocC  = j
              endif
      ENDDO

* search LocC to the LEFT of the window if LocC = locLOW
      IF ( LocC .eq. locLOW ) THEN
            iflag = 0
            j     = locLOW
 10         continue
            if( ydata(j) .ge. ydata(j-1) ) then
                  LocC  = j        ! get LocC
                  iflag = 1
            endif
            j = j - 1
            if ( j .le. (LocB+10)) go to 15
            if ( iflag .eq. 0 ) go to 10
 15      continue
      ENDIF

* search LocC to the RIGHT of the window if LocC = locHGH
      IF ( LocC .eq. locHGH ) THEN
            iflag = 0
            j     = locHGH
 20         continue
            if ( ydata(j) .ge. ydata(j+1) ) than
                  LocC  = j        ! get Loc C
```

```
                iflag = 1
           endif
           j = j + 1
           if ( j .ge. nopt ) go to 25
           if ( iflag .eq. 0 ) go to 20
25         continue
      ENDIF
      peakC = ydata( LocC )
      if(peakC.eq.0.0)go to 100         ! no peak detected

* REMARK for peakC location :
* normally, locC is some value between locLOW < locC < locHGH
* if locC = locLOW or locC = locHGH, check the Cwindow parameter
* and adjust the width accordingly.

************************
* dielectric constant *
*      of ASPHALT      *
************************
      rho      = ( peakA/fpamp ) * (-1.0)
      permASP = ( (1-rho)*(1-rho) )/( (1+rho)*(1+rho) )

**********************
* ASPHALT depth (mm) *
**********************
      mmASP = int( ( 6.0 * float( LocC-LocA ) ) / permASP**0.5 )

*******
* RMS *
*******
      RMS = 0.0
      do j = LocB, nopt
             rms = rms + (ydata(j)*ydata(j))
      enddo
      RMS = ( rms/float(nopt-LocB+1) )**0.5

      GO TO 300

************************
*        report        *
* corrupted waveforms *
************************
100   CONTINUE
      LocA    = 999
      LocB    = 999
      LocC    = 999

      mmASP   = 999
      permASP = 999.

      peakB   = 999.
      peakC   = 999.

      RMS     = 99.999999

300   CONTINUE

*********
* debug *  write processed data to DEBUG.MTO opened in pwave91.for
*********
      if ( isave .eq. 1 ) then

      write( 20, 40 ) i10count, LocA, LocB, LocC, mmASP, permASP, peakA,
     +peakC, iaveC, mmC, LocC1, LocC2, RMS
40    format(1x,i5,2x,3(i3,1x),1x,i3,2x,f10.4,2x,2(f10.6,1x),1x,i3,1x,
     +i3,2x,2(i3,1x),1x,f10.6)

      endif

      RETURN
      END
```

```
$storage:2

* v.01 FEB 04.91  v.02 FEB 06.91   v.03 FEB 20.1991

* FL/c TABLE91.for

      SUBROUTINE TABLE91 (TITLE, NUMLINE, FTRAMP, ASPSCALE,
     +                          WHEEL, RANGE, STEP)

      PARAMETER ( MAXLINE  = 16  )
      PARAMETER ( MaxLEN   = 100 )  ! max output 100m per time

      CHARACTER TITLE*(*), clearscreen*4
      INTEGER*2 oneASP, aveASP

      common /BLK2/ NUMCYCLE( MAXLINE ), mmASP, ASPdc

      DIMENSION oneASP( MaxLEN, MAXLINE ), aveASP( MAXLINE )
      DIMENSION doASP( MAXLINE ), dc( MaxLEN, MAXLINE )
      CLEARSCREEN = char(27)//'['//'2'//'J'

      OPEN ( 10, file = 'PRN' )

*=====================================================
*| FILE = SUMMARY.MTO ( 20, UNKNOWN, FORMATTED, WRITE ) |
*| open/close                                          |
*=====================================================
      OPEN ( 20, file = 'SUMMARY.MTO',status='unknown',form='formatted')
           rewind( 20 )

* calculate average bridge length over NUMLINE run
      sum = 0
      DO  I  = 1, NUMLINE
              Blength  = float( NUMCYCLE( I ) ) * wheel
              sum      = sum + Blength
      ENDDO
      BLENGTH  = sum/float( NUMLINE )
      Clength   = Blength / STEP               ! save bridge length

* set counters for fifth wheel
      Ibeg = 1
      Iend = NINT( Clength )
      IF ( Iend  .gt. Maxlen ) Iend = Maxlen

* write to printer and SUMMARY.MTO opened in THETABLE.for
      write ( 10, '(1H1,/,1x,a/)' ) ' [ SUMMARY ]'
      write ( 20, '(1x,/,1x,a/)'  ) ' [ SUMMARY ]'

      CALL GETDAT ( iyr, imon, iday )
      CALL GETTIM ( ihr, imin, isec, i100th )
      write ( 10, 5 ) imon,iday,iyr,ihr,imin,isec,i100th
      write ( 20 ,5 ) imon,iday,iyr,ihr,imin,isec,i100th
5     format(1x,'DATE = ',i2,1x,i2,'.',i4,10x,'TIME = ',i2,3(':',i2))

      write ( 10, '(1x,/,1x,a/)' ) TITLE
      write ( 20, '(1x,/,1x,a/)' ) TITLE
      write ( 10, 10 ) BLENGTH, NUMLINE
      write ( 20, 10 ) BLENGTH, NUMLINE
10    format(1x,'AVERAGE Bridge Length = ',f10.2,' metres ',
     +        5x 'NUMBER of LINES processed = ',i2,/)

      write ( 10, 20 ) ( I, I = 1, NUMLINE )
      write ( 20, 20 ) ( I, I = 1, NUMLINE )
20    format(4x,'METRES',4x,i2,19(12x,i2))
      write ( 10, 30 )
      write ( 20, 30 )
30    format(1x,240('-'))

      nLOC = 0        ! global counter for fifth wheel
100   CONTINUE

*===========================================================
*| FILE = TABLE.MTO ( 30, OLD, UNFORMATTED, READ, SIGNALAD.for) |
*| open/close                                                 |
*===========================================================
* get the TABLE.MTO file
      OPEN ( 30,file='TABLE.MTO',status='OLD',form='unformatted' )
      rewind ( 30 )

      DO J = 1, NUMLINE

              endJ = float( numcycle(J) ) * wheel/ step
              Jend = NINT( endJ )

              kk   = 0
              do K = 1, Jend

* read TABLE.MTO opened in THETABLE.for
                      READ( 30 ) mmASP, permdc
                      if ( K .ge. Ibeg .and. K .le. Iend ) then
                           kk = kk + 1
                           oneASP ( kk, J ) = mmASP
                               DC ( kk, J ) = permdc
                      endif
              enddo

              if ( Jend .lt. Iend ) then
                   jj = Clength - Jend
                   do K = 1, jj
```

```
                                kk = kk + 1
                                oneASP ( kk, J ) = 999
                                    DC ( kk, J ) = 99.99
                         enddo
                    endif

* read TABLE.MTO opened in
                    READ( 30 ) IaveASP, AdcASP

                    aveASP ( J ) = IaveASP
                    dcASP  ( J ) = AdcASP

          ENDDO
          CLOSE ( 30 )

          DO I = 1, kk
                    xLOC = xLOC + step
* this includes the dielectric constant of asphalt
                    write(10,40) xLOC, (oneASP(I,j), j= 1,NUMLINE)
                    write(20,40) xLOC, (oneASP(I,j), j= 1,NUMLINE)
 40                 format(1x,f10.2,3x,16(i4,1x,1x,5x,1x,2x))
          ENDDO

          Ibeg = Iend + 1
          Imid = Clength - Ibeg + 1
          IF ( Imid .GT. Maxlen ) Imid = Maxlen
          Iend = Ibeg + Imid - 1
          IF ( Ibeg .le. Clength ) GO TO 100

* OVERALL averages parameters
          IaveASP  = 0
          AdcASP   = 0.0

          DO I = 1, NUMLINE
                    IaveASP  = IaveASP  + aveASP ( I )
                    AdcASP   = AdcASP   + dcASP  ( I )
          ENDDO

          IaveASP  = IaveASP  /        NUMLINE
          AdcASP   = AdcASP   / float( NUMLINE )

          write ( 10, '(1H1,/,1x,a)' ) ' [ SUMMARY ]'
          write ( 20, '(1x,/,1x,a)' ) ' [ SUMMARY ]'
          write ( 10, '(1x,/,1x,a/)' ) TITLE
          write ( 20, '(1x,/,1x,a/)' ) TITLE

          call GETTIM ( ihr, imin, isec, i100th )
          write ( 10, 5 ) imon,iday,iyr,ihr,imin,isec,i100th
          write ( 20 ,5 ) imon,iday,iyr,ihr,imin,isec,i100th

          write ( 10, 220 ) FPAMP
          write ( 20, 220 ) FPAMP
 220      format(1x,/,' [ FLAT PLATE AMPLITUDE ]  = ',f10.4,' v')
          write ( 10, 240 ) WHEEL
          write ( 20, 240 ) WHEEL
 240      format(1x,/,' [ FIFTH WHEEL ]           = ',f10.4,' m')
          write ( 10, 242 ) RANGE
          write ( 20, 242 ) RANGE
 242      format(1x,/,' [ Pavement Range ]        = ',f10.4,' m')
          write ( 10, 246 ) STEP
          write ( 20, 246 ) STEP
 246      format(1x,/,' [ OUTPUT FORMAT ] every   = ',f10.4,' m')
          write ( 10, 250 ) ASPHALT
          write ( 20, 250 ) ASPHALT
 250      format(1x,/,' [ ASPHALT core sample ]   = ',f5.1,' mm')

          write ( 10, '(a/)' )' [ AVERAGE DIELECTRIC CONSTANT OF ASPHALT ]'
          write ( 20, '(a/)' )' [ AVERAGE DIELECTRIC CONSTANT OF ASPHALT ]'
          write ( 10, 120 ) ( I, I = 1, NUMLINE )
          write ( 20, 120 ) ( I, I = 1, NUMLINE )
 120      format(1x,15x,i2,19(6x,i2))
          write ( 10, 60 )
          write ( 20, 60 )
 60       format(1x,171('-'))
          write ( 10, 70 ) ( dcASP( i ), i = 1, numline )
          write ( 20, 70 ) ( dcASP( i ), i = 1, numline )
 70       format(12x,20(3x,f6.2))

          write ( 10, '(1x,/,1x,a/)' ) ' [ AVERAGE ASPHALT THICKNESS ]'
          write ( 20, '(1x,/,1x,a/)' ) ' [ AVERAGE ASPHALT THICKNESS ]'
          write ( 10, 120 ) ( I, I = 1, NUMLINE )
          write ( 20, 120 ) ( I, I = 1, NUMLINE )
          write ( 10, 60 )
          write ( 20, 60 )
          write ( 10, 110 ) ( aveASP( i ), i = 1, numline )
          write ( 20, 110 ) ( aveASP( i ), i = 1, numline )
 110      format(1x,'millimetres',3x,i4,19(4x,i4))

* write overall results
          write ( *,*) clearscreen
          CALL GETTIM ( ihr, imin, isec, i100th )
          write ( *, 5 ) imon,iday,iyr,ihr,imin,isec,i100th
          write ( *, '(1x,a)' ) TITLE

          write ( 10, '(1x,/,1x,a/)' ) '[ OVERALL AVERAGE ]'
          write ( 20, '(1x,/,1x,a/)' ) '[ OVERALL AVERAGE ]'
          write (  *, '(1x,a/)' ) '[ OVERALL AVERAGE ]'
          write ( 10, 280 ) AdcASP
          write ( 20, 280 ) AdcASP
```

```
        write (  *, 280 ) AdcASP
  280   format(1x,'[ dielectric constant of aspahlt ] = ',f10.6,/)
        write ( 10, 290 ) iaveASP
        write ( 20, 290 ) iaveASP
        write (  *, 290 ) iaveASP
  290   format(1x,'[ asphalt thickness (mm) ]         = ',i4,/)

        write ( 10,'(1H1)')
        write ( 10,'(1H1)')
        close ( 10 )
        close ( 20 )

        RETURN
        END

```

```
$storage:2

* v.01 AUG 29.1990   v.02 AUG 31.1990   v.03 FEB 05.1991
* v.04 FEB 13.1991   v.05 FEB 18.1991   v.06 FEB 19.1991
* v.07 FEB 22.1991

* plot multiple RESIDUE waveform at given STEP SIZE

* FL MTOSCAN.for /link GRAFVG40+PLOTMS4

        program MTOSCAN

        character ERROR*35, CLEARSCN*4, RFILE*15, KEY

        parameter( mWAVE  = 250,
     +             mdim   = 300,
     +             n325   = 325,
     +             ERROR  = ' -----> INPUT ERROR, try AGAIN')

* watch out mdim = 300 to allow (stepsize/wheel) average
* mdim will grow and cause overflow error if (1/.01)=100, but
*                                           (10/.01)=1000 !! alarming

       common /plt/  cdata(n325), sdata(n325,mdim)
       common/blk2/ xdata(n325), ydata(512), zdata(n325)
       common/blk3/ clip, izoom, zoom, ipks, thold, iskew
       common/blk4/ xmin, xmax, xminplt, xmaxplt, ymin, ymax,
     +              Y0, Ywave, Aymin, Aymax

 99    continue
       CLEARSCN = char(27)//'['//'2'//'J'    ! clear screen
       write(*,*) clearscn

       write(*,'(a\)')' [input] DATA FILE name (*.mto)                  : '
       read(*,'(a)') RFILE
       write(*,'(a\)')'          Total # of waveform                    : '
       read(*,*) NTR

 110   continue
       write(*,'(a\)')'          FIFTH wheel pulse (m) [min 0.01 m]     : '
       read(*,*) wheel
       stepMIN = wheel
       stepMAX = wheel * 100.0
       if(NTR.lt.100)stepMAX = wheel * float(ntr)
 102   write(*,104) stepMIN, stepMAX
 104   format(1x,/,9x,'MINImum STEP size is : ',f10.2,' metres',/,
     +             9x,'MAXImum STEP size is : ',f10.2,' metres',/)

       if ( NTR .gt. mWave) then
            stepOpt = float(ntr)/float(Mwave) * wheel
            write(*,106) stepOpt
 106        format(9x,'suggested STEP size = ',f10.6,' metres')
       endif
       write(*,*)' '
       write(*,'(a\)')'          desire STEP size (m)                   : '
       read(*,*) stepsize
       if ( stepsize .lt. stepMIN .OR. stepsize .gt. stepMAX ) then
            write(*,'(a)') ERROR
            go to 102
       endif

* get first waveforms to be plotted
       MAXPLT = NINT( float( NTR ) / ( stepsize/wheel ) )
       NUMPLT = NINT(float(MAXPLT)*(stepsize/wheel))

       if ( NUMPLT .lt. NTR   ) MAXPLT = MAXPLT+1
       NUMPLT = MAXPLT
       if ( MAXPLT .gt. Mwave ) MAXPLT = Mwave

       write(*,5) maxplt, NUMPLT
 5     format(1x,/,9x,'# of waveforms/plot (max ',i3,'/',i4,')  : ',\)
       read(*,*)maxplt
 4     write(*,'(a\)')'          FIRST waveform to plot                 : '
       read(*,*)ifirst
       if(ifirst.le.0.or.ifirst.gt.ntr)then
          write(*,'(a)') ERROR
          go to 4
       endif

* last waveform to be plotted
       ILAST = NINT(float(ifirst)+(float(MAXPLT)*(stepsize/wheel))-1.0)

 8     write(*,'(a\)')'          [SMOOTHing data] 0-no, 1-yes           : '
       read(*,*)ismooth
       if(ismooth.lt.0.or.ismooth.gt.1)then
          write(*,'(a)') ERROR
          go to 8
       endif

 9     write(*,'(a\)')'          [STC] 0-no, 1-yes                      : '
       read(*,*)istc
       if(istc.lt.0.or.istc.gt.1)then
          write(*,'(a)') ERROR
          go to 9
       endif

       ibeg=ifirst
       iend=ilast
```

```
      IF ( iend .gt. NTR ) iend = ntr

      numsig=iend-ibeg+1
      write(*,6) ibeg, iend, numsig, ntr
6     format(1x,/,9x,'plot waveform # ',i5,' to ',i5,' (total ',i5,
     +'/',i4,' waveforms)',/)

* set counter
      icount=0
      jwave =0
      iskip=0
      mskip=0
      nskip=0
      do 13 i=1,n325
              xdata(i)=0.0      ! clear vector for overall average
13    continue

      OPEN ( 5, file = RFILE , status = 'old', form = 'unformatted' )
      rewind(5)

      DO 16 I=1,IEND

              read(5)  (ydata(j), j=1,512)

              if( I .LT. IBEG ) GO TO 16

              icount=icount+1 "
*             write(*,7)i
*7            format(1h+,8x,'processing trace : ',i5)

* smoothing data
              IF ( ismooth .eq. 1 ) THEN
                  iSMave = 5                 !  (5-point sliding average)
                  m1     = 1
                  m2     = m1 + iSMave - 1
                  m3     = 0
12                Asum   = 0
                  do J   = m1, m2
                             Asum = Asum + ydata(j)
                  enddo
                  m3          = m3 + 1
                  ydata(m3) = Asum/float( m2-m1+1 )
                  m1          = m1 + 1
                  m2          = m2 + 1
                  if( m2 .ge. n325 ) m2 = n325
                  if( m1 .le. n325 ) go to 12
              ENDIF

* search surface echo
              maxpk = 132
              pkmax = 0.0
              do j = 1, n325
                     if(ydata(j).ge.pkmax)then
                        pkmax  = ydata(j)
                        maxpk  = j
                     endif
              enddo

* STC
              if(istc.eq.1)then
                slope=(10.0-1.0)/(float(n325-maxpk))
                do j=1,n325
                        cdata(j)=1.0
                        if (j.ge.maxpk) then
                            cdata(j)=(slope*float(j-maxpk))+1.0
                        endif
                        zdata(j)=ydata(j)
                        ydata(j)=ydata(j)*cdata(j)
                enddo
                pkA = 0.0
                do j =1,n325
                        if(ydata(j).ge.pka)then
                           pka=ydata(j)
                           maxpk=j
                        endif
                enddo
              endif

* Line up peak A wrt to point 135 (5.40 ns)
              do 26 j=1,n325
                      sdata(j,icount+jwave)=0.
26            continue

* if peakA is less than 2.5v
* or if peakA is located less than 125 sample or over 150 sample
* then declare 'CORRUPTED DATA'

      write(*,7)i, maxpk, pkmax
7     format(1h+,8x,'processing trace : ',i5,' pkA = ',i3,1x,f10.6)
              istop = icount + jwave
              if(istop.gt.mdim) go to 1000

              if(maxpk.le.120.or.maxpk.ge.150.or.pkmax.lt.2.0)then
                 iskip=iskip+1
                 nskip=nskip+1
                 go to 200
              endif
               maxA=135
```

```
                jj=0
                do 23 j=maxpk,n325
                        jj=jj+1
                        k=maxA+jj-1
                        if(k.gt.n325)go to 23
                        sdata(k,icount+jwave)=ydata(j)
 23             continue
                jj=0
                do 24 j=maxA-1,1,-1
                        jj=jj+1
                        k=maxpk-jj
                        if(k.le.0)go to 24
                        sdata(j,icount+jwave)=ydata(k)
 24             continue

 200            continue
                do j = 1,n325
                      ydata(j) = 0.0
                enddo

* calculate wave ave
                MAVE = NINT( stepsize/wheel )
                NAVE = (NTR/MAVE) * MAVE
                if ( i .gt. NAVE ) MAVE = NTR - NAVE

                IF(icount.eq.mave)THEN
                   jwave=jwave+1
                   do 205 j=jwave,icount+jwave-1
                            do 210 k=1,n325
                                     ydata(k)=ydata(k)+sdata(k,j)
 210                        continue
 205               continue

                   if(iskip.eq.mave)then
                      mskip=mskip+1
                      do 215 j=1,n325
                               sdata(j,jwave)=0.
 215                  continue
                   else
                      do 220 j=1,n325
                               sdata(j,jwave)=ydata(j)/float(mave-iskip)
                               xdata(j)=xdata(j)+ydata(j)
 220                  continue
                   endif

* normalize sdata(.) for stack plot
                   datmax=0.0
                   do 38 j=1,n325
                           big=sdata(j,jwave)
                           if(abs(big).gt.datmax) datmax = abs(big)
 38                continue
                   do 40 j=1,n325
                           if(datmax.ne.0.)then
                              sdata(j,jwave)=sdata(j,jwave)/datmax
                           else
                              sdata(j,jwave)=0.0
                           endif
 40                continue
                   iskip=0
                   icount=0
                ENDIF

 16     CONTINUE
        close(5)

        NWAVE = Jwave
        write(*,225) Nwave, mskip
 225    format(9x,'... will plot ',i5,' waveforms ... (',i5,') corrupted')

* overall average waveform
        ymin=0.
        ymax=0.
        do 240 i=1,n325
                 if(numsig.eq.nskip)then
                    cdata(i) = 0.0
                 else
                    cdata(i)=xdata(i)/float(numsig-nskip)
                 endif
                 if(cdata(i).ge.ymax) ymax = cdata(i)
                 if(cdata(i).le.ymin) ymin = cdata(i)
 240    continue

 100    continue
        call MULSCN(Nwave,ERROR)

        write(*,'(a\)')'          <cr> skip plotter, o/w any key       : '
        read(*,'(a)') key
        if(key.ne.' ') CALL MULPLT(Nwave)

        write(*,'(a\)')'          <cr> plot MORE, o/w any key          : '
        read(*,'(a)') key
        if(key.eq.' ') go to 100
        go to 2000

 1000   write(*,1002)i,icount,jwave,istop,mdim
 1002   format(1x,/,1x,' overflow error at index (ISTOP)',1x, 'I=',i5,
       +' icount=',i5,' jwave=',i5,' istop=',i5,' mdim=',i5,/)

 2000   write(*,'(a\)')'          <cr> change FIFTH/ETC, o/w any key  : '
```

```fortran
      read(*,'(a)') key
      if(key.eq.' ') go to 110

      write(*,'(a\)')'         <cr> to INPUT NEW file, o/w any key : '
      read(*,'(a)')key
      if(key.eq.' ')go to 99

      END

*******************************************
      SUBROUTINE MULSCN(Nwave,ERROR)
*******************************************
      parameter( mWAVE = 250,
     +           mdim  = 300,
     +           n325  = 325)

      common/plt/ cdata(n325), sdata(n325,mdim)
      common/blk2/ xdata(n325), ydata(512), zdata(n325)
      common/blk3/ clip, izoom, zoom, ipks, thold, iskew
      common/blk4/ xmin, xmax, xminplt, xmaxplt, ymin, ymax,
     +             Y0, Ywave, Aymin, Aymax
      dimension wdata(n325)
      character ERROR*(*), KEY

      step  = 1
      n     = n325

      iscale = NINT(float(Nwave)/2.0)
      write(*,2) iscale
 2    format(1x,/,9x,'suggested scaling factor = ',i5,/)
      write(*,'(a\)')'         [SCALing factor]                     : '
      read(*,*) clip

 3    write(*,'(a\)')'         [ZOOM] 0-no, 1-yes                   : '
      read(*,*)izoom
      if(izoom.lt.0.or.izoom.gt.1) then
         write(*,'(a)') ERROR
         go to 3
      endif
      if(izoom.eq.1)then
         write(*,'(a\)')'         zoom factor (5 to 20 or more)        : '
         read(*,*)zoom
      endif
 4    write(*,'(a\)')'         [OPT] 0-complete, 1-peak, 2-valley   : '
      read(*,*) ipks
      if(ipks.lt.0.or.ipks.gt.2)then
         write(*,'(a)') ERROR
         go to 4
      endif
      if(ipks.ne.0)then
         write(*,'(a\)')'         threshold level (normally 0.0)       : '
         read(*,*) THOLD
      endif

      write(*,'(a\)')'         [SKEW] how many sample               : '
      read(*,*)iSKEW
      skew = float(nwave)*float(iSKEW)*0.04

      if(iSKEW.eq.0)then
         write(*,'(a\)')'         [Xaxis] xmin, xmax (0,13)            : '
         read(*,*)xmin,xmax
      else
         xmin = 0.0
         xmax = 13.0
      endif
      xminplt=xmin
      xmaxplt=xmax
      if( iSKEW .gt. 0 ) xmaxplt = skew + xmax
      if( iSKEW .lt. 0 ) xminplt = skew + xmin
      if( iSKEW .ne. 0 ) then
        write(*,5)xminplt,xmaxplt
 5      format(1x,/,9x,'skew window : xmin = ',f5.2,' xmax = ',f5.2)
        write(*,'(a\)')'          [NEW x-axis] xmin, xmax               : '
        read(*,*)xminplt, xmaxplt
      endif

      y0    = 0.0
      ywave = 0.0
      IMIN = int(xminplt*25.0)
      if(imin.le.0)imin = 1
      IMAX = int(xmaxplt*25.0)
      if(imax.ge.n)imax=n

      do j =imin,imax
            ymx = sdata(j,nwave)*clip+nwave
            if(ymx.ge.ywave)ywave=ymx
            ym0 = sdata(j,1)*clip+1
            if(ym0.le.y0) y0=ym0
      enddo

      if(ipks.ne.2.and.IZOOM.eq.1)Ywave=(float(Nwave)+(0.2*clip))*ZOOM
      if(ipks.eq.2.and.IZOOM.eq.1)Ywave=(float(Nwave))*ZOOM
      if(ipks.eq.2.and.IZOOM.eq.0)Ywave=float(Nwave)
      if(ipks.eq.1) y0 = 0.0
      if(ipks.ne.1.and.IZOOM.eq.1) y0 = y0 * zoom
      write(*,14) Y0, Ywave
 14   format(1x,/,9x,'suggested y-MIN = ',f8.2,' y-MAX = ',f8.2)
      write(*,'(a\)')'         give y-MIN and y-MAX                 : '
      read(*,*) y0, Ywave
      write(*,16)
16    format(1x,/,9x,'- AVERAGE waveform - ',/)
      write(*,17)ymin,ymax
17    format(9x,'ymin=',f10.6,' ymax=',f10.6)
      write(*,18)
18    format(1x,/,9x,'[input] ymin, ymax = ',\)
      read(*,*)Aymin,Aymax


15    write(*,'(a\)')'         [STACK+AVE]-1, [combine]-2          : '
      read(*,*)iplot
      if(iplot.le.0.or.iplot.gt.2)then
         write(*,'(a)') ERROR
         go to 15
      endif

      istack= 1
      iave  = 0
      istop = 0
      Iwave = nwave

      yminp=y0
      ymaxp=Ywave

      if(iplot.eq.1)then
         jcol1=100
         jcol2=500
         jrow1=50
         jrow2=300
      else
         jcol1=60
         jcol2=300
         jrow1=45
         jrow2=144
      endif

99    xminp=xminplt
      xmaxp=xmaxplt

      if(iave.eq.1)then
         istop=1
         yminp=Aymin
         ymaxp=Aymax
         if(iplot.eq.2)then
            jcol1=400
            jcol2=599
         endif
         iwave   = 1
         xmaxp   = xmax
      endif

      xorg=xminp
      yorg=yminp
      if(iave.eq.1)yorg=0.0

      xdiff=xmaxp-xminp
      xmaj = 1.
      if(xdiff.ge.15.or.iplot.eq.2)xmaj=2.
      if(xdiff.ge.40)xmaj=5.
      if(xdiff.gt.100)xmaj=10.

      ydiff=ymaxp-yminp
      if(ydiff.le.1)   ymaj =  0.2
      if(ydiff.ge.2)   ymaj =  0.5
      if(ydiff.ge.5)   ymaj =  1
      if(ydiff.ge.10)  ymaj =  2
      if(ydiff.ge.50)  ymaj = 10
      if(ydiff.ge.100) ymaj = 20
      if(ydiff.ge.250) ymaj = 50
      if(ydiff.ge.500) ymaj =100
      if(ydiff.ge.1000)ymaj =200
      if(ydiff.ge.2000)ymaj =500
      ndec = 0
      if(ydiff.le.100)ndec=1

      ratio = 1.28
      yoverx=(ymaxp-yminp)/(xmaxp-xminp)
      ymx=ymaxp
      if(iplot.eq.1)then
         call qsmode(17)
      else if(istop.eq.0)then
         call qsmode(17)
      endif
      call qplot(jcol1,jcol2,jrow1,jrow2,xminp,xmaxp,yminp,ymx,xorg,yorg
     +           ,1,yoverx,ratio)
      call qsetup(0,1,-2,1)
      call qcolor(1,0)
      call qxaxis(xminp,xmaxp,xmaj,0,-1,0)
      call qyaxis(yminp,ymaxp,ymaj,0,-1,ndec)

      delta  = 0.0               ! stack step
      idelay = 0                 ! skew delay
      DO 20 i=1,Iwave
            jcnt = 0             ! overlapping counter
            rms = 0.0
            ipt = 0
            DO 30 j = IMIN, IMAX
                  ipt        = ipt + 1
```

```
                    mSKEW      = j   + idelay
                    zdata(ipt) = sdata(j,i)
                    xdata(ipt) = float(mSKEW)*0.04

* PEAKs/Valleys
                    if( (ipks.eq.1.and.zdata(ipt).le.thold) .or.
     +                   (ipks.eq.2.and.zdata(ipt).ge.thold) )
     +                  zdata(ipt) = thold
* RMS values
                    if(xdata(ipt).ge.xmin.and.xdata(ipt).le.xmax)
     +                 rms = rms + (zdata(ipt)*zdata(ipt))

                    ydata(ipt)=0.0
                    if(istack.eq.1)then
                      ydata(ipt)=zdata(ipt)*clip+(1.*delta)+step
                      if(izoom.eq.1)ydata(ipt)=ydata(ipt)*zoom
                    endif

* remove overlapping
                    if(iSKEW.ne.0)then
                       if(i.ne.1)then
                          jn = ipt + iSKEW
                          if( jn.gt.0 .and. jn.le.IMAX )then
*                             if( ydata(ipt).gt.wdata(jn) ) jcnt = 0
                              if( ydata(ipt).le.wdata(jn) ) then
                                 jcnt = jcnt + 1
*                                zdata(jcnt) = ydata(ipt)
                                 ydata(ipt)  = wdata(jn)
                              endif
                          endif
                       endif
                    endif
                    if(iave.eq.1) ydata(ipt)=cdata(j)

                   if(ydata(ipt).le.yminp)ydata(ipt)=yminp
                   if(ydata(ipt).ge.ymaxp)ydata(ipt)=ymaxp
                   if(xdata(ipt).le.xminp)xdata(ipt)=xminp
                   if(xdata(ipt).ge.xmaxp)xdata(ipt)=xmaxp
30             continue

               if( iSKEW .ne. 0 )then
*                if(jcnt.ne.0) then    ! for remove overlapping line
*                   do j = 1,ipt
*                         ydata(ipt-jcnt+j-iSKEW) = zdata(j)
*                   enddo
*                 endif
                  do j = 1,ipt
                        wdata(j) = ydata(j)
                  enddo
                endif

                rms = (rms/((xmax-xmin)*25.))**0.5
                if( iave .ne. 0 ) then
                    write(*,35)i,Nwave,rms,xmin,xmax
35                  format(1h+,' waveform # ',i3,'/',i3,' RMS=',f10.6,
     +                       ' from ',f5.2,' ns to ',f5.2,' ns')
                endif

                npt   = IMAX - IMIN + 1
                call qtabl(1,npt,xdata,ydata)
                delta = delta+step
                idelay= idelay + iSKEW

20    CONTINUE

       istack=0
       iave=1
       if(iplot.eq.1)then
          read(*,'(a)')key
       endif
       if(istop.eq.0)go to 99
       if(iplot.eq.2)then
          read(*,'(a)')key
       endif
       call qsmode(3)
       call qclear(0,2)
       write(*,'(a\)')'       <cr> next view, any key to repeat   : '
       read(*,'(a)') key
       if(key.ne.' ')go to 15

       RETURN
       END

****************************************
      SUBROUTINE MULPLT(Nwave)
****************************************
      parameter ( Nwave = 250,
     +            mdim  = 300,
     +            n325  = 325)

      common/plt/ cdata(n325), sdata(n325,mdim)
      common/blk2/ xdata(n325),ydata(512),zdata(n325)
      common/blk3/ clip, izoom, zoom, ipks, thold, iskew
      common/blk4/ xmin, xmax, xminplt, xmaxplt, ymin, ymax,
     +            YO, Ywave, Aymin, Aymax
      dimension wdata(n325)
      character name*15, title*35

      istack=1
```

```
        iave=0
```

```
        istop=0

        step=1

        Iwave = Nwave
        n     = n325

        do 10 i=1,n
                xdata(i)=0.
                ydata(i)=0.
 10     continue

        write(*,12)
 12     format(1x,/,9x,'[Title] 35 charac : ',\)
        read(*,'(a)')title

        write(*,26)
 26     format(1x,/,9x,' ... plot stacking waveforms ....',/)

 99     continue

        xst =xminplt
        xfin=xmaxplt

        yst= y0
        yfin=Ywave

        if(iave.eq.1)then
           istop=1
           xfin =xmax
           yst  =Aymin
           yfin =Aymax
           write(*,'(a/)')'          ... plot average waveform ...'
        endif

        write(*,50)
 50     format(1x,'[select plot size] FULL page (1)',/,20x,'LEFT page (2)'&
       +/,20x,'RIGHT page (3)',/,20x,'CENTRE page (4)',/,20x,'UPPER LEFT',&
       +' (5)',/,20x,'LOWER LEFT (6)',/,20x,'UPPER RIGHT (7)',/,20x,      &
       +'LOWER RIGHT (8)',/,20x,'others size (9)',/,20x,'QUIT (0) ... ',\)
        read(*,*)isize
        if(isize.eq.0)go to 100

        if(isize.eq.9)then
           write(*,51)
 51        format(1x,'[full size] x1=0, x2=10400, y1=250, y2=8000')
           write(*,52)
 52        format(1x,'[input new size] x1, x2, y1, y2 : ',\)
           read(*,*)jx1,jx2,jy1,jy2
        endif
        ic1 = 0
        ic2 = 10365
        ir1 = 250
        ir2 = 7962

* isize=1 full size
        jc1= ic1
        jc2= ic2
        jr1= ir1
        jr2= ir2

* isize=2 LEFT page
        if(isize.eq.2)jc2=ic2/2

* isize=3 RIGHT page
        if(isize.eq.3)jc1=ic2/2

* isize=4 Centre page
        if(isize.eq.4)then
           jc1=ic2/4
           jc2=ic2-(ic2/4)
        else  if(isize.eq.5)then
                jc1=0
                jc2=ic2/2
                jr1=ir2/2
                jr2=ir2
        else  if(isize.eq.6)then
                jc1=0
                jc2=ic2/2
                jr1=ir1
                jr2=(ic2/2)+ir1
        else  if(isize.eq.7) then
                jc1=ic2/2
                jc2=ic2
                jr1=ir2/2
                jr2=ir2
        else  if(isize.eq.8) then
                jc1=ic2/2
                jc2=ic2
                jr1=ir1
                jr2=(ir2/2)+ir1
        else  if(isize.eq.9) then
                jc1=jx1
                jc2=jx2
                jr1=jy1
                jr2=jy2
        endif
```

```
      xo=xst
```

```
      yo=yst
      xrange=xfin-xst
      yrange=yfin-yst
      xbeg=xst-xrange/5.
      xend=xfin+xrange/5.
      ybeg=yst-yrange/5.
      yend=yfin+yrange/5.
      if(isize.eq.1.or.xrange.lt.20)xmaj=1.
      if(xrange.ge.20)xmaj=2.
      if(xrange.ge.50)xmaj=10.
      if(xrange.gt.100)xmaj=20.

      ymaj=abs(yfin-yst)/(yfin-0.025)
      if(yrange.le.1)   ymaj=  0.2
      if(yrange.ge.2)   ymaj=  0.5
      if(yrange.ge.5)   ymaj=  1
      if(yrange.ge.10)  ymaj=  2
      if(yrange.ge.50)  ymaj= 10
      if(yrange.ge.100) ymaj= 20
      if(yrange.ge.250) ymaj= 50
      if(yrange.ge.500) ymaj=100
      if(yrange.ge.1000)ymaj=200
      if(yrange.ge.2000)ymaj=500
      ndec = 0
      if(yrange.le.100)ndec=1
      if(yrange.le.1)  ndec=2

      name='scratch.dat'
      xlabel='ns'
      ylabel=' v'

      call zinit(2,1,name)
      call zplot(jc1,jc2,jr1,jr2,xbeg,xend,ybeg,yend,xo,yo)
      call zxaxis(xst,xfin,xmaj,1,-1,0)
      ilabel=0
      if(iave.eq.1)ilabel=-1
      call zyaxis(yst,yfin,ymaj,1,ilabel,ndec)
      if(iave.eq.1) title='        Average Waveform'

      x1=(float(jc2)-float(jc1))/(xend-xbeg)
      x2=float(jc1)-(xbeg*x1)
      y1=(float(jr2)-float(jr1))/(yend-ybeg)
      y2=float(jr1)-(ybeg*y1)

      if(iave.eq.1)Iwave=1

* enclose box
      xi=(x1*xminplt)+x2
      ix=int(xi)
      yi=(y1*yfin)+y2
      iy=int(yi)
      call zpu
      call zpa(ix,iy)
      call zpd
      xi=(x1*xmaxplt)+x2
      ix=int(xi)
      call zpa(ix,iy)
      yi=(y1*yst)+y2
      iy=int(yi)
      call zpa(ix,iy)
      call zpu

      IMIN = int(xminplt*25.0)
      if(imin.eq.1)IMIN=1
      IMAX = int(xmaxplt*25.0)
      if(imax.ge.n)imax=n

      delta = 0.
      idelay= 0
      do 22 i=1,Iwave
              jcnt = 0
              ipt  = 0
              do j = IMIN, IMAX
                      ipt   = ipt + 1
                      mSKEW = j + idelay
                      zdata(ipt) = sdata(j,i)
                      xdata(ipt) = float(mSKEW)*0.04

* PEAKS/VALLEY
                      if( (ipks.eq.1.and.zdata(ipt).le.thold) .OR.
     +                    (ipks.eq.2.and.zdata(ipt).ge.thold) )
     +                    zdata(ipt)=thold
              enddo

              write(*,30)i
30            format(1h+,9x,'plotting waveform # ',i5,' [wait]')

              if(istack.eq.1)then
                 ydata(1)=zdata(1)*clip+(1.*delta)+step
                 if(izoom.eq.1) ydata(1) = ydata(1) * zoom
              endif
              if(iave.eq.1) ydata(1) = cdata(IMIN)

              if(ydata(1).le.yst) ydata(1)=yst
              if(ydata(1).ge.yfin) ydata(1)=yfin

              if(xdata(1).le.xminplt)xdata(1)=xminplt
              xi=(x1*xdata(1))+x2
              ix=int(xi)
              yi=(yl*ydata(1))+y2
              iy=int(yi)

              call zlt(-1,0,0)
              call zpu
              call zpa(ix,iy)
              call zpd

              do 24 j=2,IPT
                      if( xdata(j).le.xminplt
     +                    .or. xdata(j).ge.xmaxplt) go to 24

                      if(istack.eq.1)then
                         ydata(j)=zdata(j)*clip+(1.*delta)+step
                         if(izoom.eq.1)ydata(j)=ydata(j)*zoom
                      endif

* remove overlapping
                      if( iSKEW .ne. 0 )then
                          if( i.ne.1 ) then
                              jn = j + iSKEW
                              if(jn.gt.0 .and. jn.le.IMAX)then
*                                 if(ydata(j).gt.wdata(jn)) jcnt = 0
                                  if(ydata(j).le.wdata(jn)) then
                                     jcnt = jcnt + 1
*                                    zdata(jcnt) = ydata(j)
                                     ydata(j)    = wdata(jn)
                                  endif
                                endif
                           endif
                      endif

                      if(iave.eq.1) ydata(j) = cdata(IMIN+j-1)

                      if(ydata(j).le.yst.or.ydata(j).ge.yfin)go to 24
                      xi=(xl*xdata(j))+x2
                      ix=int(xi)
                      yi=(yl*ydata(j))+y2
                      iy=int(yi)
                      call zpa(ix,iy)
24            continue

              if( iSKEW .ne. 0 )then
*                 if( jcnt.ne.0 )then
*                     do j =1,ipt
*                           ydata(ipt-jcnt+j-iSKEW) = zdata(j)
*                     enddo
*                  endif
                   do j = 1,ipt
                          wdata(j) = ydata(j)
                   enddo
              endif
              idelay = idelay + iSKEW
              delta  = delta  + step
22      continue
        call zpu

        if(iave.eq.1)then
           call ZSP(1)
           xi=(xl*xminplt)+x2
           ix=int(xi)
           yi=y2
           iy=int(yi)
           call zpu
           call zpa(ix,iy)
           call zpd
           xi=(xl*xmaxplt)+x2
           ix=int(xi)
           call zpa(ix,iy)
           call zpu
        endif
        call ziw(jc1,jr1,jc2,jr2,0)
        call zptxtb(3,xlabel,1)
        call zptxtc(3,ylabel,1)
        call zptxta(35,title,1)

        call zfinis
        istack=0
        iave=1
        if(istop.eq.0)go to 99

        call ZSP(0)
100     continue
        return
        end
```